Make: High-Power Rockets

Construction and Certification for Thousands of Feet and Beyond

Mike Westerfield

Make: High-Power Rockets

by Mike Westerfield

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Preface

If you’ve read *Make: Rockets*, you already know the profound impact model rocketry has had on my life, as well as how I enjoy sharing my enthusiasm for it with others. There is one update that I do want to share: I now have two grandsons who have taken up rocketry. I am happy to report that I’ve started them off right. Both of them learned to count down before they learned to count up! I do feel a little bad for getting Coen in trouble, though. In a moment of excitement, he grabbed a houseplant by the stem. “5-4-3-2-1,” and the plant left the pot.

This book picks up where its predecessor left off. *Make: Rockets* covers basic rocket science, including construction, aerodynamics, simulation, tracking, and electrical engineering. The rockets in that book are made from thin, lightweight materials that are extremely safe. Some projects work well with young children, while others will challenge a college engineering student.

High-power rocketry is different, though. While there is a junior-level certification (covered in “NAR junior certification”), high-power rocketry is otherwise restricted to people over 18. High-power rockets can easily break the sound barrier, shooting miles into the sky. The rockets themselves are not the small, collapsible paper rockets flown in schools and scouting—they are often metal-tipped, fiberglass missiles that weigh tens or even hundreds of pounds. FAA clearances and certifications are required.

That’s what this book is all about. It explains how to build and fly high-power rockets, and how to get your high-power rocketry certifications. You will find comprehensive information about safety, legal issues, and construction techniques for these larger rockets, as well as study tips to help you prepare for the certification exams. The book is designed to fill a practical void. While everything you need to know to get your certifications is certainly available in various books, magazine articles, and websites, it is not collected in one place or organized so you can easily find the information you need at each certification level. In fact, as I researched some aspects of this book, I found that many resources are outdated or incorrect, especially when it comes to rocketry's legal considerations.

If your goal is to learn how to build and fly rockets that use H or larger motors, this is the book for you!

Conventions Used in This Book

The following typographical conventions are used in this book:

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Indicates new terms, URLs, email addresses, filenames, and file extensions.

`Constant width`

Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names.

TIP

This element signifies a tip, suggestion, or general note.

WARNING

This element indicates a warning or caution.

Using Designs

Supplemental material (rocket simulations, code examples, exercises, etc.) is available for
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Acknowledgments

Like many of you, my start in rocketry came from learning about a local rocketry club and going out to see what they were all about. I started meeting new friends immediately. Jim Jewell, the club webmaster and semi-official photographer, befriended me first, offering initial encouragement and pointing me to the best sources of information at the time. He also lent me a GPS tracker that appears in

some of this book’s illustrations, and you will find some of his photos scattered throughout, too.

Bill Beggs and Tony Lazzaro are our local TAP officials. They mentored me as I got my own Level 1, 2, and 3 certifications. Tony also led the Baby-Q project, which flew with 13 M motors at BALLS 23. Being a junior team member on that project was an amazing experience I will always treasure.

Many members of the Albuquerque Rocket Society, Flare Rocketry, and Alamogordo Rocketry also helped as I got my certifications and wrote this book. It was Bob Finch, for example, who first showed me the burrito fold for parachutes. Several others provided photos or built rockets that appear in photos throughout the book, including Stephen Forbes, Ken Goldstein, Kevin Small, and Todd Kerns.

Todd also gets a special thanks for doing a technical review of the book on a very tight timeline. He found several small errors, and gave advice on how to improve the section on testing ejection charges.

A great deal of the information in this book comes from various manufacturers and organizations. This includes tables, photographs, and safety codes. Thank you to the many people who kindly gave me permission to include material in this book, including Charles Savoie of AeroTech Consumer Aerospace, Paul Haydon of Armag Corporation, Gene Engelgau of Fruit Chutes, John Hochheimer from the National Association of Rocketry, Frank “Rocketman” Uroda of Public Missiles Ltd., and Steve Shannon from the Tripoli Rocketry Association.

Some manufacturers kindly provided samples of products for the book. One stands out: Barry Lynch from LOC Precision not only supplied parts, he also took the time to provide personal introductions to many other people in the industry, as well as answering a number of questions about high-power rocketry. Barry was one of the key people to show me that big rockets did not necessarily have to be built from fiberglass or carbon fiber, something that had an impact on many aspects of the book. One of the people he introduced me to was Missile Works Corporation’s Jim Amos, who kindly supplied the RRC2+ and RRC3 altimeters you’ll see featured in the book. Another was Cesaroni Technology Incorporated’s Sandi White, who sent a great care package with much of the CTI hardware I used while writing the book. Bob Mosley of Aero Pack, Inc., donated two unusual motor retainers for photos. I also want to thank Doug Pratt for the Microbeacon. The generosity of these people helped make this book far more complete and better rounded than it would have been without their support.

Chapter 1. Mid- and High-Power Rocketry

As you drive into the countryside for your first high-power launch, get ready for an amazing experience. Depending on the size of the club or the event you pick, there may be anywhere from a half dozen to a few hundred amateur rocket scientists at the event. Some of the rockets will leap from the pad, quickly breaking the sound barrier. Others will be giant works of art that seem like they belong at a space facility. Depending on the altitude restrictions the FAA has placed that day, some of the rockets might fly several miles high. As you feel the roar from the larger rockets vibrate your body, you’re going to want to know how to build and fly your own high-power rockets!

That’s what this book is all about.

What Is High-Power Rocketry?

You may have already flown one of the small black powder rockets that are common in schools and scouting programs, and in kits that can be found at most hobby stores. There is a qualitative difference between those kits and high-power rockets. It’s not just size, although that is a big part of the difference. There are also differences in the materials used to build the rockets, differences in the kinds of rocket motors used, and even differences in the laws that cover this type of rocketry. Based on the various rules and laws, amateur rocket scientists typically divide rocketry into four categories: low-power rocketry, mid-power rocketry, high-power rocketry, and amateur rocketry. This book is mostly about high-power rocketry, although the rocket in the first project can be flown as a mid-power rocket, and the last chapter guides you into amateur rocketry.

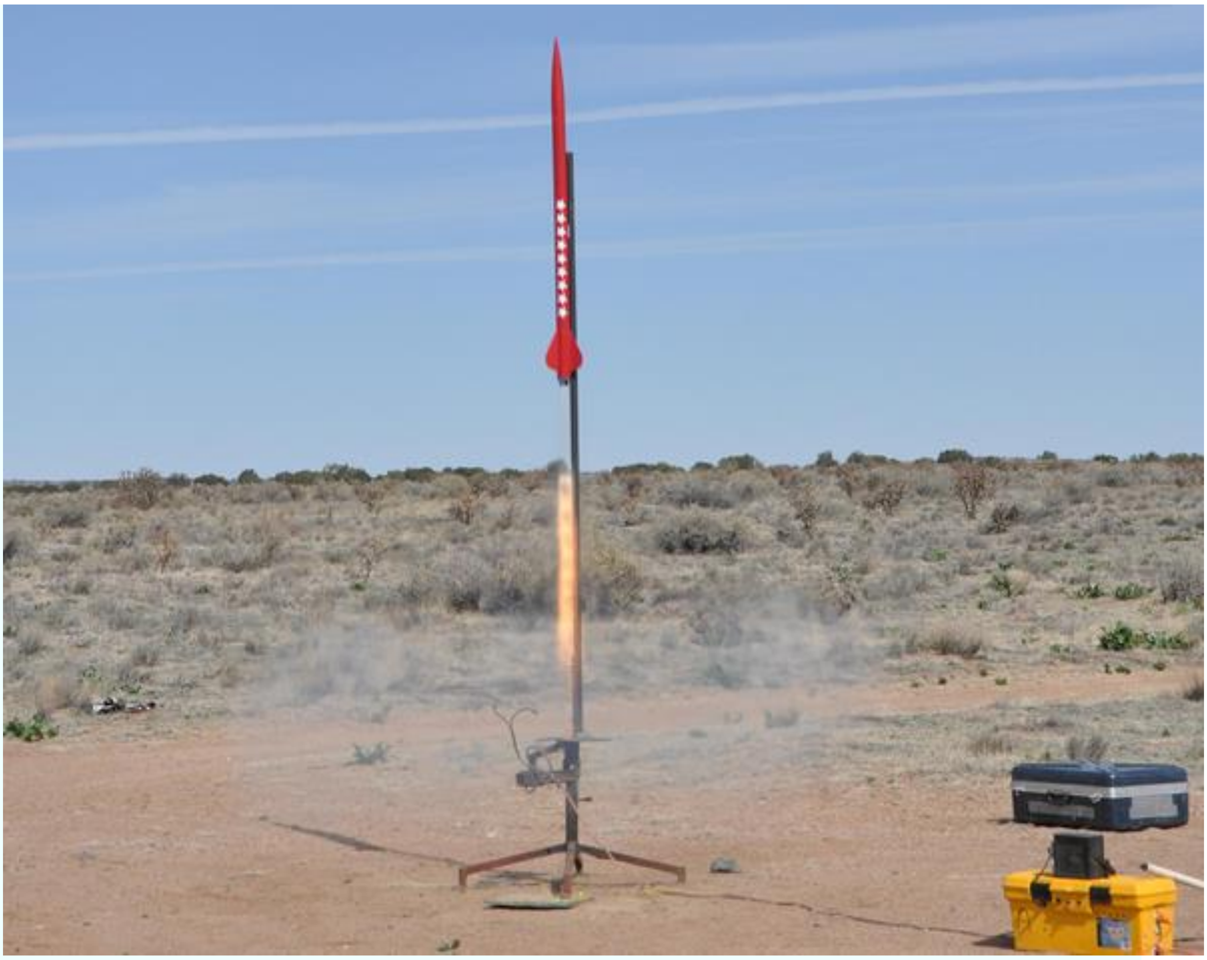


Figure 1-1. Todd Kerns's Space Cowboy lifts off. The exhaust plume clearly shows Mach diamonds, a standing wave that can appear in supersonic exhaust plumes. Photo by Jim Jewell.

The categories are largely distinguished by the power of the rocket motor. Let's start by looking at how rocket motors are rated by power.

Rocket Motors by Total Impulse

Rocket motors are classified by their *total impulse*, or the power they deliver. Total impulse is measured in *newton-seconds*, abbreviated N-s. A newton is a measure of force, the amount needed to accelerate 1 kilogram of mass at the rate of 1 meter per second squared. The designation doesn't tell us the actual force generated by the motor, just the overall power. A rocket motor that delivers a force of 10 newtons for 1 second has the same overall power rating as a motor that delivers 5 newtons for 2 seconds.

The motors are divided into letter groups based on this total impulse, where each letter group has twice the total power of the previous group. A small black powder motor like you find at a hobby store is typically an A, B, or C motor. The A motor has up to 2.5 N-s of power, the B motor has more power than the A (between 2.5 and 5 N-s), and the C motor has anywhere between 5 and 10 N-s. Since each letter represents twice the power of the previous letter, the power rises quickly. High-power rocketry starts with H motors, which have 128 times the power of an A motor, or up to 320 N-s. The Mercury Redstone that carried the first two American astronauts into space was a Z motor. A Z motor can have over 33 million times the power of an A motor!

Table 1-1 shows the maximum total impulse for the various rocket motor classifications. While there are a few corner cases we'll look at later, it also shows how we divide rocketry up by the power of the motor. Low-power rocketry includes most of what you will find at a typical hobby store. Low-power rockets use motors with a total impulse of 40 N-s or less—E motors or smaller. Mid-power rocketry includes F and G motors. High-power rocketry picks up with H motors and ends with O motors. Anything over an O motor is generally called amateur rocketry.

Class	Maximum total impulse (N-s)	Example
1/4 A	0.625	Low-power rocketry
1/2 A	1.25	
A	2.5	
B	5	
C	10	
D	20	
E	40	
F	80	Mid-power rocketry

Class	Maximum total impulse (N-s)	Example
G	160	
H	320	High-power rocketry
I	640	
J	1,280	
K	2,560	
L	5,120	
M	10,240	
N	20,480	
O	40,960	Largest high-power motor
P	8.19E+04	Sidewinder air-to-air missile
Q	1.64E+05	The Baby Q from Chapter 14
R	3.28E+05	
S	6.55E+05	
T	1.31E+06	
U	2.62E+06	Orion Launch Abort Rocket
V	5.24E+06	
W	1.05E+07	
X	2.10E+07	
Y	4.19E+07	
Z	8.39E+07	Mercury Redstone

Class	Maximum total impulse (N-s)	Example
2Z	1.68E+08	
3Z	3.36E+08	Mercury Atlas
4Z	6.71E+08	Gemini Titan
5Z	1.34E+09	
6Z	2.68E+09	Space Shuttle
7Z	5.37E+09	
8Z	1.07E+10	Saturn V

Table 1-1. Rocket motor classification

Rocket Motor Labels

There are several varieties of commercially available mid- and high-power rocket motors. We’ll return to this topic in Chapter 4, when we build high-power motors from the two biggest manufacturers, AeroTech and Cesaroni. For now, though, let’s wrap up our discussion of motor designations by taking a look at a typical high-power motor. Figure 1-2 shows the motor case and reload for an AeroTech H128W-M.

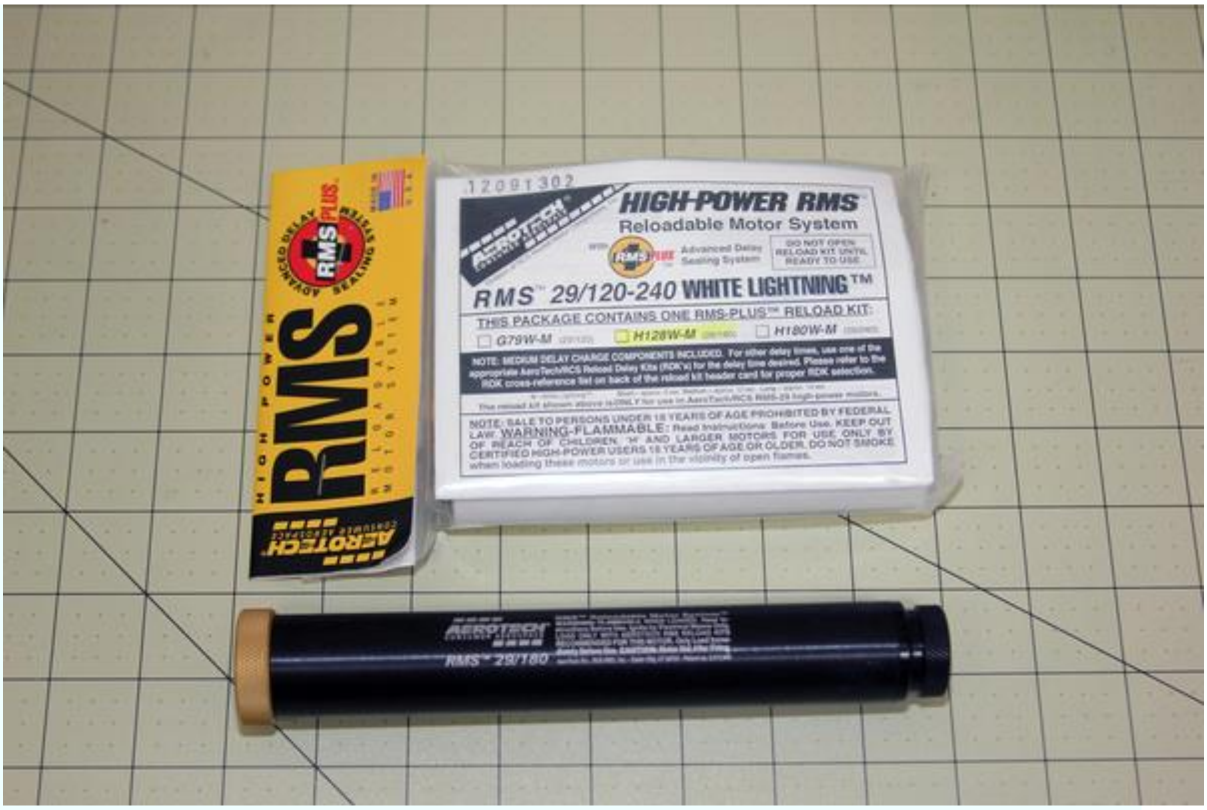


Figure 1-2. The motor case and reload for the H128W-M.

Like most high-power motors, even the Space Shuttle Solid Rocket Booster (SRB), this one has some parts you reuse and some parts you throw away. The black anodized aluminum tube and the two closures, one brass colored and one black anodized aluminum, are reused. We'll return to this motor in "Building the AeroTech H128W-M" and take a look at how the motor cases are labeled.

The bag contains the parts that are thrown away after the flight, which are collectively called the *reload*. This includes the rocket fuel, a nozzle, a smoke delay, and an ejection charge; a liner to protect the motor case; and several washers and O-rings that keep the rocket's flaming gases from damaging the motor case. This reload is called the H128W-M, and each of those letters and numbers means something (see Figure 1-3).

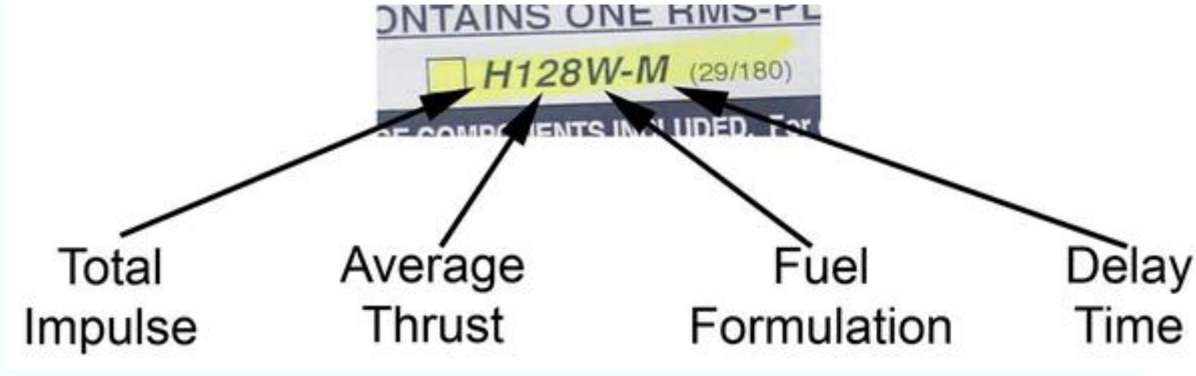


Figure 1-3. The H128W-M motor label.

You’ve already seen what H means. This tells us right away that we are looking at a high-power motor that will deliver more than 160 N-s but no more than 320 N-s of total impulse.

Total impulse tells us the overall power of a motor, but it says nothing about whether this power is delivered fast or slowly. The second number gives us some idea of the overall thrust of the motor. The 128 in the motor designation tells us this motor delivers an average of 128 newtons of thrust. This does not tell us everything we need to know about the thrust curve of the motor, but it’s a good way to quickly distinguish between fast-burning, powerful motors (such as the AeroTech H268R-M) and long-burning motors that deliver less thrust (such as the H97J-M).

The next letter tells us a bit about the rocket fuel itself. Most high-power motors use ammonium perchlorate for rocket fuel—the same fuel used by the Space Shuttle SRB. They frequently dope the motor with additional compounds to change the burn rate or create colored flames or smoke. The letter tells us what specific fuel formulation is used. The W in H128W-M stands for White Lightning. These motors look and sound the most like those in the sounding rockets used for weather and atmospheric testing. You get a brilliant white flame and white smoke. We’ll return to motor fuels in Chapter 4 and take a detailed look at the various formulations.

Finally, the letter M tells us this is a medium-duration ejection charge. Cesaroni uses a number instead, indicating the actual delay in seconds.

Low-Power Rocketry

Low-power rockets, such as the one shown in Figure 1-4, usually use single-use black powder motors. The propellant is a mixture of potassium nitrate, sulfur, and charcoal with a binder used to hold it all together. The rockets are most often made from a thin, collapsible paper tube with balsa wood or plastic fins and nose cones. The vast majority of low-power rockets weigh less than a pound and fly to an altitude of less than 2,500 feet.

Low-power rocketry has been around since the late 1950s. Over the years the hobby has built an astounding safety record. If you have not built a rocket before, low-power rocketry is a great place to start. If you’re new to rocketry, you will of course make mistakes, some of which could result in a rocket going awry. Such mistakes are a lot easier to bounce back from when your only loss is an inexpensive, low-power rocket, instead of a high-power rocket that might cost several hundred dollars. And while you might feel differently when collecting your shredded rocket from wherever it has landed, it’s also nice when the misbehaving rocket collapses on impact, as this significantly reduces the chances of it harming whatever it might hit.

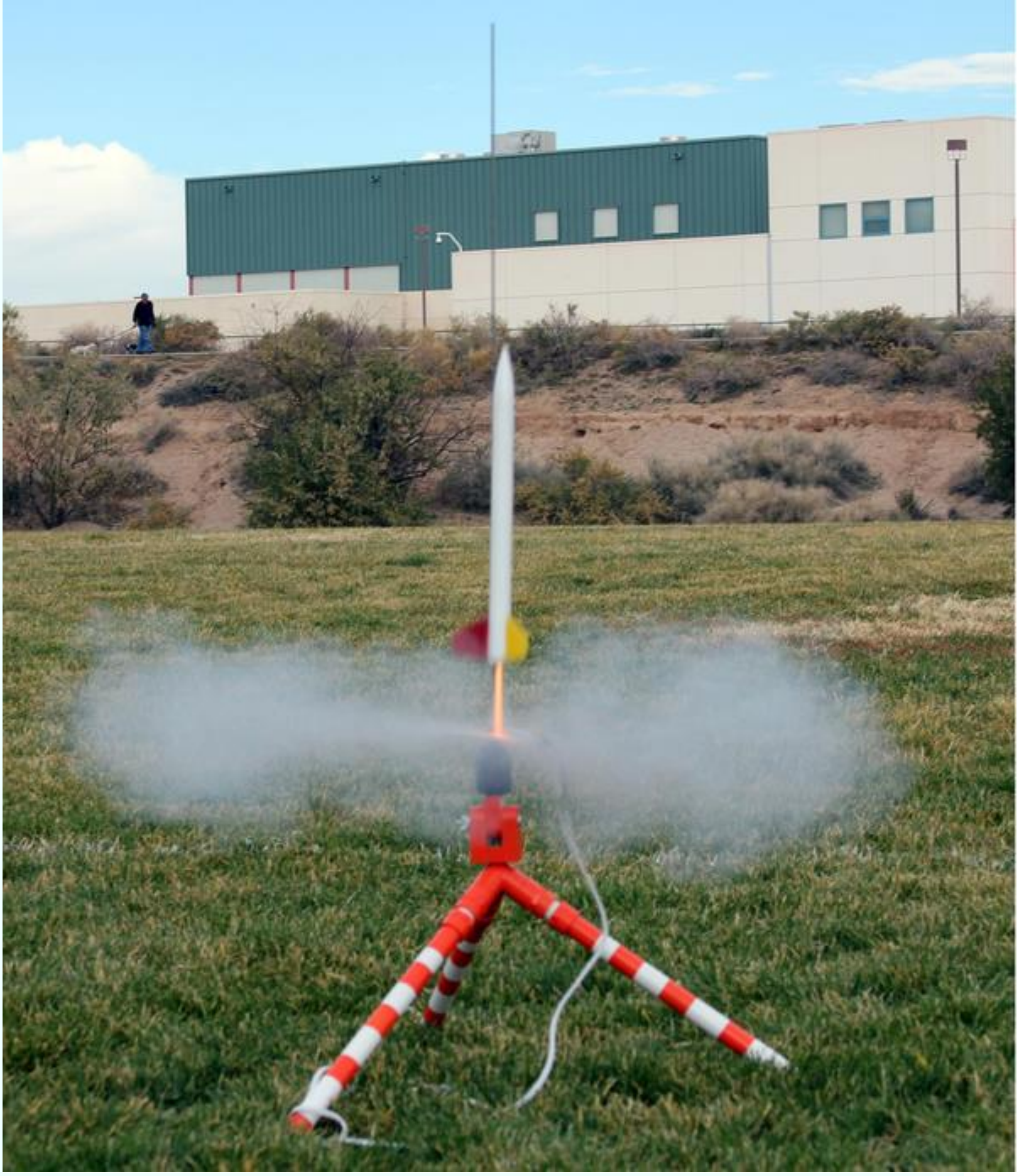


Figure 1-4. Juno, a low-power rocket from Make: Rockets, lifts off from a local park.

I’ve met a few people whose first rocket was a high-power rocket. If you’ve never built a rocket of any kind before, though, you should seriously consider starting off with a low-power rocket to get some experience.*Make: Rockets* covers low-power rocketry in detail, showing how to build and fly rockets up through E power. It includes two-stage rockets, cluster rockets that use more than one motor, rocket gliders, and rockets that return using helicopter recovery.

Mid-Power Rocketry

While there are good reasons to quibble about a few boundary cases, most people consider mid-power rockets to be any rockets that use an F or G motor. Some mid-power rockets use black powder motors that are somewhat larger versions of the motors used in low-power rocketry. Others use reloadable rocket motors that are smaller versions of the motors used in most high-power rockets. Many mid-power rockets are built with paper tubes, plastic nose cones, and wooden fins, but the paper tubes are generally much thicker than those used for low-power rockets, and the fins are usually aircraft plywood instead of balsa wood. In almost all important ways, the construction techniques and materials are similar to those in high-power rocketry. However, there are two things that make it worth keeping mid-power rockets in a category by themselves.

First, you don’t have to be certified to fly mid-power rockets, whereas flying high-power rockets (which includes all rockets that use an H power motor or higher) requires a certification. We’ll talk about the certification process in a moment, but it’s not optional for high-power rocketeers. Leaving aside the fact that it is not legal to fly high-power rockets unless you are certified or making a flight to get certified, there is also the practical problem that companies that sell high-power rocket motors won’t sell you a motor unless you are certified.

The other big dividing line between mid-power and high-power rockets is that most high-power rockets require an FAA Class 2 clearance. That’s right, you have to clear your flight with the FAA, just like anyone else using the airspace to fly a large vehicle that could potentially cause problems with air traffic. You need an FAA clearance for most rocket flights that use an H motor or larger, or smaller motors that add up to the same total impulse as an H motor (just to confuse things, there are a few H motors that don’t require a Class 2 clearance). All ammonium perchlorate motors require at least a Class 1 clearance, though. We’ll look at those restrictions in Chapter 11.

This book covers mid-power rocketry, too. The next chapter shows you how to build Callisto, a rocket designed to fly on both mid-power and small high-power motors (see Figure 1-5). You can fly Callisto on an F or most G motors without an FAA Class 2 clearance, and then you can pack a high-power H motor into the rocket when you get together with other rocketeers for a high-power launch.

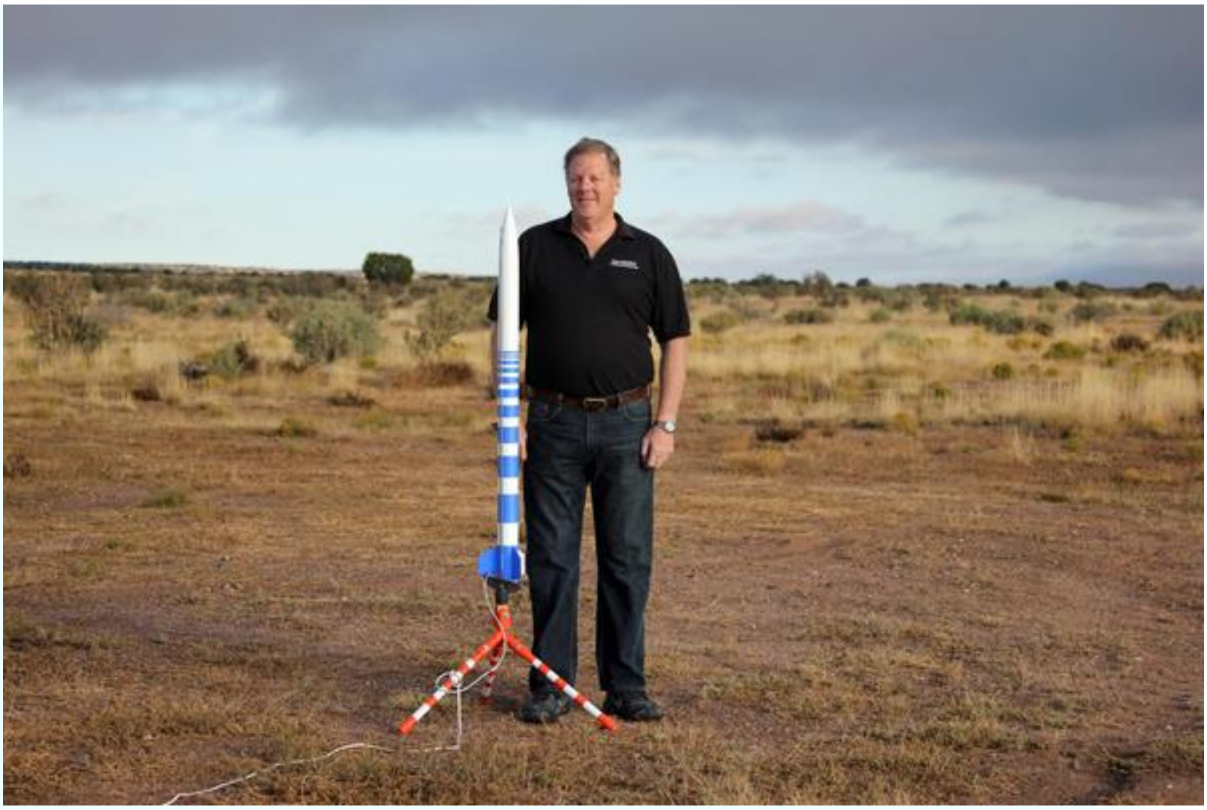


Figure 1-5. The author gets Callisto ready for a mid-power flight. You will build Callisto in Chapter 2. Note that the launcher is the same one used for Juno, the low-power rocket shown in Figure 1-4.

High-Power Rocketry

High-power rockets use H through O motors—motors with a total impulse of at least 320 N-s but less than 40,960 N-s. The main reason for the dividing line is that rockets with more than 40,960 N-s of total impulse require a different kind of FAA clearance for flight. Oversimplified a bit, H to O rockets are covered by an FAA clearance that reserves the airspace; you can fly any rocket that stays within the reserved airspace. P and higher rockets require an FAA clearance for the individual rocket flight. The FAA doesn't just give you the airspace to do what you like; you need to get approval for the design and flight profile for the individual rocket. We’ll cover the details in Chapter 11.

As I’ve said, most high-power rocket motors use ammonium perchlorate as rocket fuel. It’s not unheard of to see other rocket fuels, like black powder, but the more powerful the motor is, the less likely it is that it will use black powder. That’s because, pound for pound, ammonium perchlorate rocket fuel is about three times more powerful than black powder.

The most common alternative to an ammonium perchlorate motor is the hybrid motor. A hybrid uses liquid nitrous oxide as an oxidizer and a solid hydrocarbon such as PVC, wax, or rubber for fuel. This is the same system used by SpaceShipTwo, Virgin Galactic’s suborbital aircraft being developed for space tourism. Hybrid motors tend to cost more in terms of initial investment and are a bit more involved to fly, but they tend to cost less per flight than ammonium perchlorate motors, and there are fewer legal restrictions on this type of fuel, as you will see in Chapter 11.

We’ll look more closely at rocket fuel and the power you get from various fuels in Chapter 11. Most of the rockets in this book are designed to fly with ammonium perchlorate motors, but it’s easy to adapt many of them for hybrid motors.

High-power rocketry is open to anyone 18 or older who is certified to fly at a particular power level. Younger rocket scientists aged 14–17 can fly H and I rockets with adult sponsorship. We’ll cover the rules more completely in Chapter 11; basically, if a teenager wants to fly an H rocket, an adult high-power rocketeer has to build the motor and take responsibility for the flight.

High-power rocket certification in the United States is divided into three levels. The Level 1 certification covers H and I motors; Level 2 covers J, K, and L motors; and Level 3 covers M, N, and O motors. Let’s take a brief and simplified look at what these three levels of certification mean, and what you have to do to get certified at each level. We’ll cover the details later, as we build and fly rockets for each certification level.

The Level 1 certification is really pretty easy to get. You need to build and successfully fly a rocket powered by an H or I motor. Once certified, you can legally fly any rocket that has a total impulse of up to 640 N-s. This restriction is a law in most states, so vendors that sell high-power rocket motors and reloads won't sell you a motor unless you are certified.

Of course, that presents a catch-22. You can't buy such motors until you are certified, but you have to buy such motors to get certified. This is covered by an exception: you can buy a single H or I motor if it is bought to attempt a certification flight. If your flight fails for some reason, you can buy one more motor for the next attempt.

You will see how to build a Level 1 rocket in the next chapter. Chapter 4 walks you through the certification process, including the organizations you will need to join, how to find someone to certify you, and what to expect from the certification process.

The Level 2 certification covers rockets with a total impulse below 5,120 N-s. It's a little more challenging than the Level 1 certification. In addition to building and flying a rocket that uses a J, K, or L motor, you also need to pass a written exam. Chapter 11 tells you everything you need to know to pass the Level 2 test. Chapter 6 shows you how to build a Level 2 rocket. In fact, it shows you a lot of options for building a Level 2 rocket, including one that is a nice sport flyer and another that can blast through the sound barrier with a large J or K motor!

The Level 3 certification covers rockets with a total impulse of up to 40,960 N-s. As with the first two certification levels, the main requirement is to build and successfully fly a rocket, this time one that uses an M, N, or O motor. There are two other requirements, though. The first is to demonstrate the use of electronic deployment of the recovery system in a Level 2 rocket. This usually means you build and fly a rocket that uses *dual deployment*, where the rocket uses an altimeter to figure out when it gets to *apogee* (the highest point in the flight), then deploys a small parachute or streamer to slow it down a little, but not enough for landing. This lets the rocket fall back to a low altitude fairly quickly so it won't drift too much in the wind. At a lower latitude, generally about 1,000 feet, the rocket deploys the main parachute, which slows it down enough for a safe landing. Almost all

Level 3 rockets use dual deployment of some sort, so it makes sense to get some experience with a lower-power rocket before attempting a dual deployment flight with a large M, N, or O class rocket. You also have to create a complete engineering package for the Level 3 flight. This document describes the rocket, including construction and the expected flight profile. It's the base document that convinces your certifying official that you and your rocket are ready for the flight. It also gives the certifying official a chance to mentor you a bit, pointing out any potential problems you might have due to the design of your rocket.

In Chapter 13, we'll see how to build a 7.5-foot-long Level 3 rocket called Ganymede (see Figure 1-6). Ganymede will fly nearly 3 miles high and hit about Mach 1.5, even on a small M motor. Chapter 12 covers the certification process, including tips for filling out your Level 3 engineering document.

Figure 1-6. Ganymede, the M power rocket we'll build in Chapter 13, gets ready for liftoff at BALLS 2014. This rocket flew over 13,000 feet, hitting Mach 1.5.

Amateur Rocketry

Nothing is stopping you from flying rockets with more than 40,960 N-s of total impulse. These rockets are powerful enough that they need special permits, though. These larger rockets can fly above 50,000 feet; two have even reached space. On May 17, 2004, the 20-foot-tall GoFast rocket, built and flown by a group of amateur rocket scientists who banded together as CSXT (The Civilian Space eXploration Team), flew to an altitude of 72 miles, easily cracking the international definition of space, which is an altitude of 100 kilometers (62 miles).

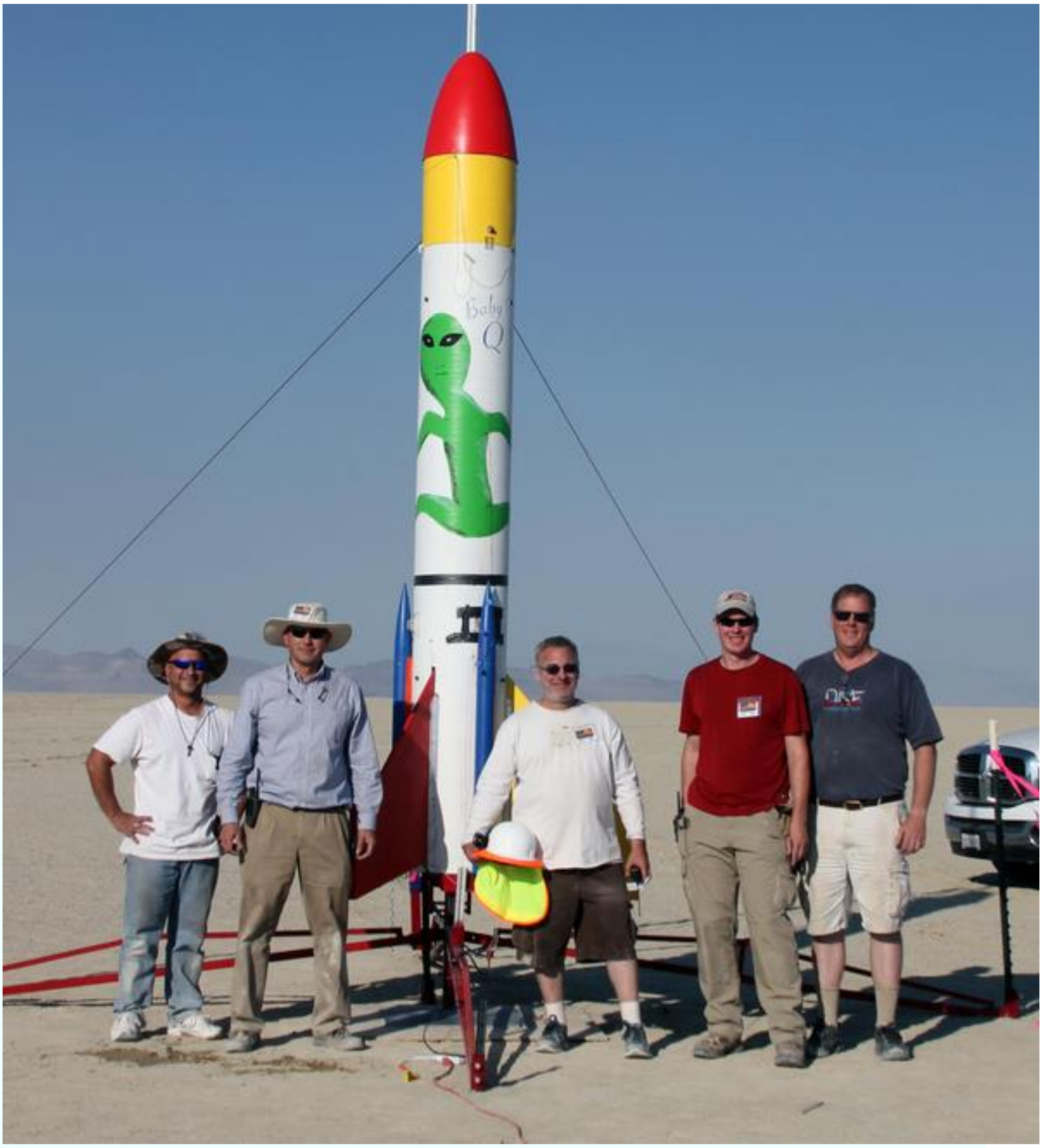


Figure 1-7. A team prepares a Q power rocket for flight at BALLS 23. From left to right, Kevin Small, Tony Lazzaro, Ken Goldstein, Stephen Forbes, and Mike Westerfield. The Baby Q used 13 M motors for a total impulse of 83,694 N-s.

Once rockets get this big, each project is a major undertaking. Chapter 14 offers some thoughts.

Joining a Club

As already mentioned, you *must* get certified to fly high-power rockets. In the United States, this means you will need to join one of two organizations that issue certifications. As a practical matter, you will also need to join a local rocket club. Let’s take a look at why you need to join these organizations and how to get your membership started.

High-power certifications in the United States are issued by either the National Association of Rocketry (NAR) or the Tripoli Rocketry Association (TRA). In Canada, similar certifications are issued by the Canadian Association of Rocketry (CAR). The law prevents vendors who sell high-power rocket motor reloads or single-use high power motors from selling you a single-use motor or reload for a reloadable motor unless you are certified to use the motor, or are buying the motor to get the certification. This means you must join one of these organizations.

NAR has been around since 1957. (The patent on the model rocket wasn’t finally granted to Orville Carlisle until 1958!) One of the primary functions of NAR has always been to keep rocketry safe. Harry Stine had a huge influence on this effort, bringing his experience as a safety officer at the White Sands Missile Range to model rocketry to help develop a safety code. The NAR safety code is still the most widely recognized and used guide to safely flying model rockets. NAR sponsors several annual events, like NARAM, which features a national competition for low-power rockets. NAR is far more active in low-power rocketry than TRA, but also covers high-power rocketry through O motors. Members receive a subscription to the print magazine *Sport Rocketry*, published six times a year, and get $2,000,000 insurance coverage for rocket mishaps. You can join NAR at the NAR website.

TRA was founded as a local rocketry organization in 1964, but really came into its own as it pushed to get high-power rocketry established in the United States. In 1985, TRA became the first rocketry organization to explicitly support high-power rocketry. TRA keeps records for a number of high-power rocketry achievements, like altitude records by motor power. It also sponsors research launches, which provide a venue for amateur rocket scientists to experiment with noncommercial motors and P and above motors, with 40,960 N-s or more of total impulse. TRA members are covered by insurance that ranges from $2,500 to $3,000,000, depending on the nature of the claim. You can join TRA at the TRA website.

The certification requirements for the two organizations are very similar. In fact, they are so similar that people who are certified through one organization can show their paperwork to the other to get their achievements recognized through that organization, too.

After joining one of these organizations, you will need to find a local certifying official who can supervise your Level 1 flight. For NAR, that can be any member of NAR who has at least a Level 2 certification, or a NAR member with a Level 1 certification plus one additional NAR member, with or without a high-power certification. For TRA, the certifying official will be a club member who is a prefect or *TAP*, a member of the TRA Technical Advisory Panel.

Almost all local rocket clubs are going to require you to join before you can fly high-power rockets with the club. This is in addition to joining NAR or TRA. While it might seem a bit onerous to join a second organization, the local club is going to do a great deal for you. The club will already have a designated launch site for flying high-power rockets, and will have FAA clearances for scheduled launch dates. Most clubs will provide high-power launchers, so you don’t need to build or own your own. Even if the club does not provide launchers, there will be several launchers at the launch, and you will be able to borrow one. My club even has a radio tracker that club members can borrow, as well as an M motor case, greatly reducing the cost of getting your Level 3 certification. Club members frequently lend hardware to one another, especially motor casings. And, of course, there is all the mentoring and advice—most of it wanted!—that you will get from the other club members. The price of membership is well worth it.

So, which organization should you join: NAR or TRA? If you also do a lot of low-power rocketry, and you’re not a member of NAR already, you should probably favor NAR. If you plan to build rockets with more than 40,960 N-s of total impulse, or you expect to fly noncommercial motors, join TRA. As for me, I joined both, since they are both great organizations. There is one other factor you might want to consider, though. If your local club is fairly small, it may not have certification officials for both organizations. If you only intend to join one or the other, find a local rocket club first and see which they recommend. Larger clubs will have members from both NAR and TRA, but they might still recommend one or the other for some reason—perhaps because of the kinds of launches they favor.

Both NAR and TRA maintain lists of local rocket clubs that are members of the national organization. Those lists will help you find a local club to join. If you are lucky enough to live in a place that has two or more nearby clubs, get in touch with all of them to find out what their members concentrate on. Try to attend a club meeting or launch so that you can meet the club members. Who knows, you might even join more than one rocket club—I know several people who belong to multiple clubs. See *http://www.nar.org/find-a-local-club/nar-club-locator/* for the NAR club locator. TRA refers to local clubs as prefectures, and you can find the list of both US and international prefectures at *http://www.tripoli.org/Prefectures*.

The Flight of a Typical High-Power Rocket

Chapter 2 shows how to build Callisto, a typical Level 1 rocket. Let’s follow Callisto through a flight to get an overview of how high-power rockets work. There are a lot of variations on the classic design of the Callisto, of course, and we’ll cover them in later chapters, but this rocket is a great place to learn the basics. There are also a few details we will gloss over in the interest of brevity. We’ll fill in the details you need for your Level 1 flight in the next few chapters.

As the launch day approaches, you’ll need to make sure you have a motor ready for the flight. You might decide to fly Callisto as a mid-power rocket on a motor like the AeroTech F52T-8, or perhaps you’re getting ready for your Level 1 certification flight with an AeroTech H128W-M or a Cesaroni H163-WT-9. In any case, you’ve selected a motor that is appropriate for the size of the flying field and the FAA clearance, if any.

As the launch approaches, you load the motor into the rocket, along with a parachute and a protective cover called the *recovery blanket*. You slide the rocket onto the launch rail or launch rod—both can be used, depending on the launcher, and Callisto is built to work with either. You insert the igniter once the rocket is on the launch pad and connect the leads from the electrical ignition system. Everything is ready for the flight! See Figure 1-8.

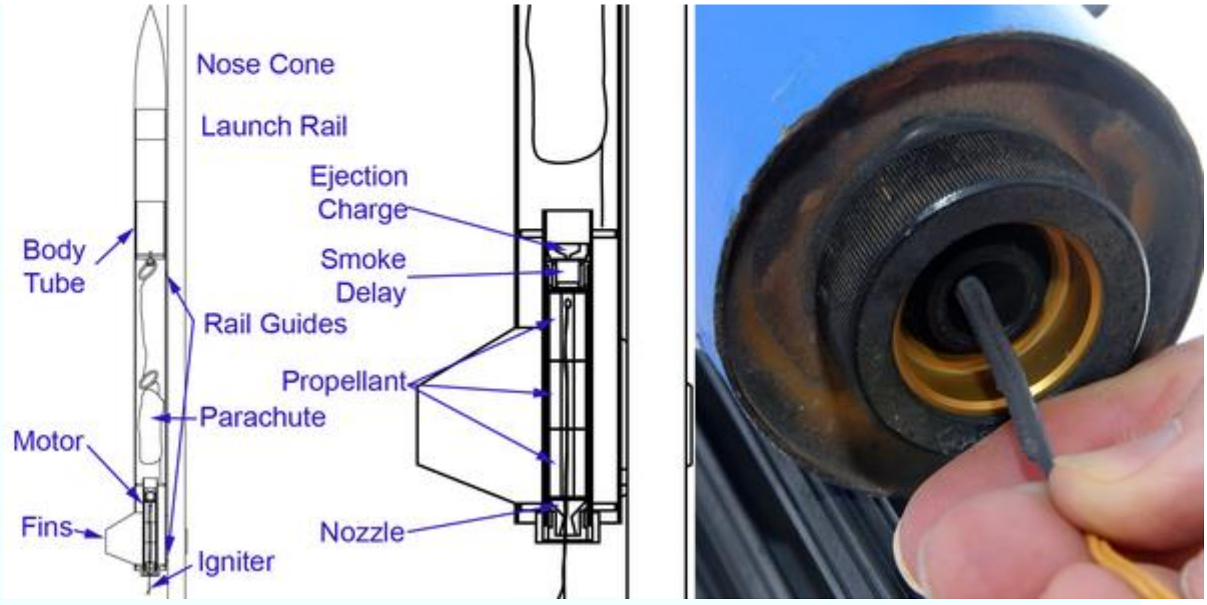


Figure 1-8. After preparing the rocket, it is slid into place on the launch pad. The igniter is inserted and the electrical ignition system is connected. The rocket is ready to launch!

After a short countdown, the launch control officer (LCO) presses the ignition button. Twelve volts of electricity flow through the igniter wire, heating it to the point that the flammable pyrogen on the tip of the igniter lights. That, in turn, starts the ammonium perchlorate burning in the rocket motor. You see Callisto’s motor light in Figure 1-9.

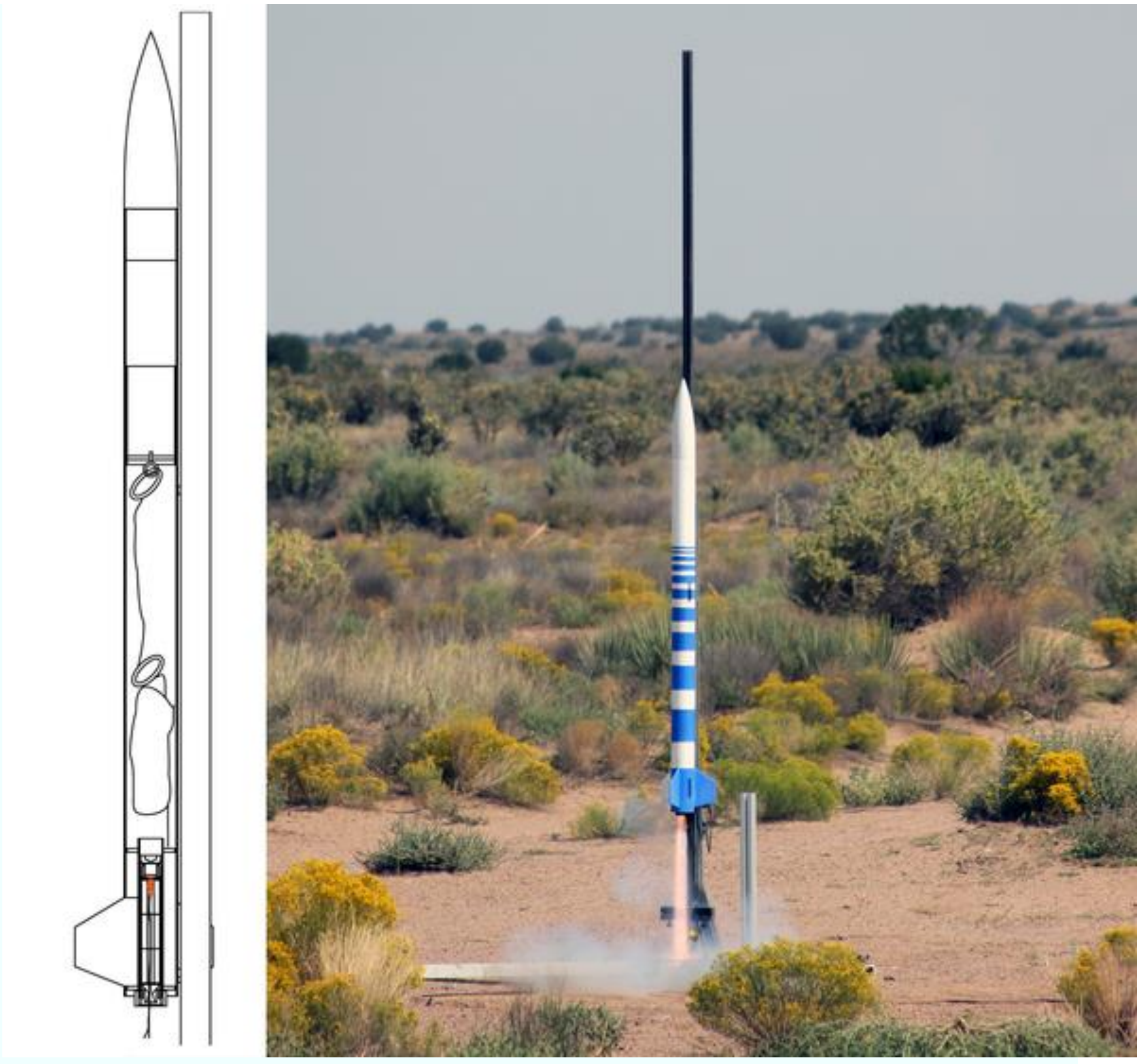


Figure 1-9. The igniter lights the rocket fuel, and the rocket begins to lift off.

The ammonium perchlorate actually takes some time to light and come up to pressure. This might be a second or so, or it could be several seconds, depending on the motor. Smoke and flame begin to shoot from the base of the rocket, and suddenly it springs to life! Like most high-power rockets, Callisto takes off fast. On a typical 6-foot-long launch rail using an H128W-M motor, it takes just 0.18 seconds to reach the end of the rail. The rocket is already traveling at 61 mph as it leaves the rail. Callisto is only about 6 feet past the launch rail in Figure 1-10.

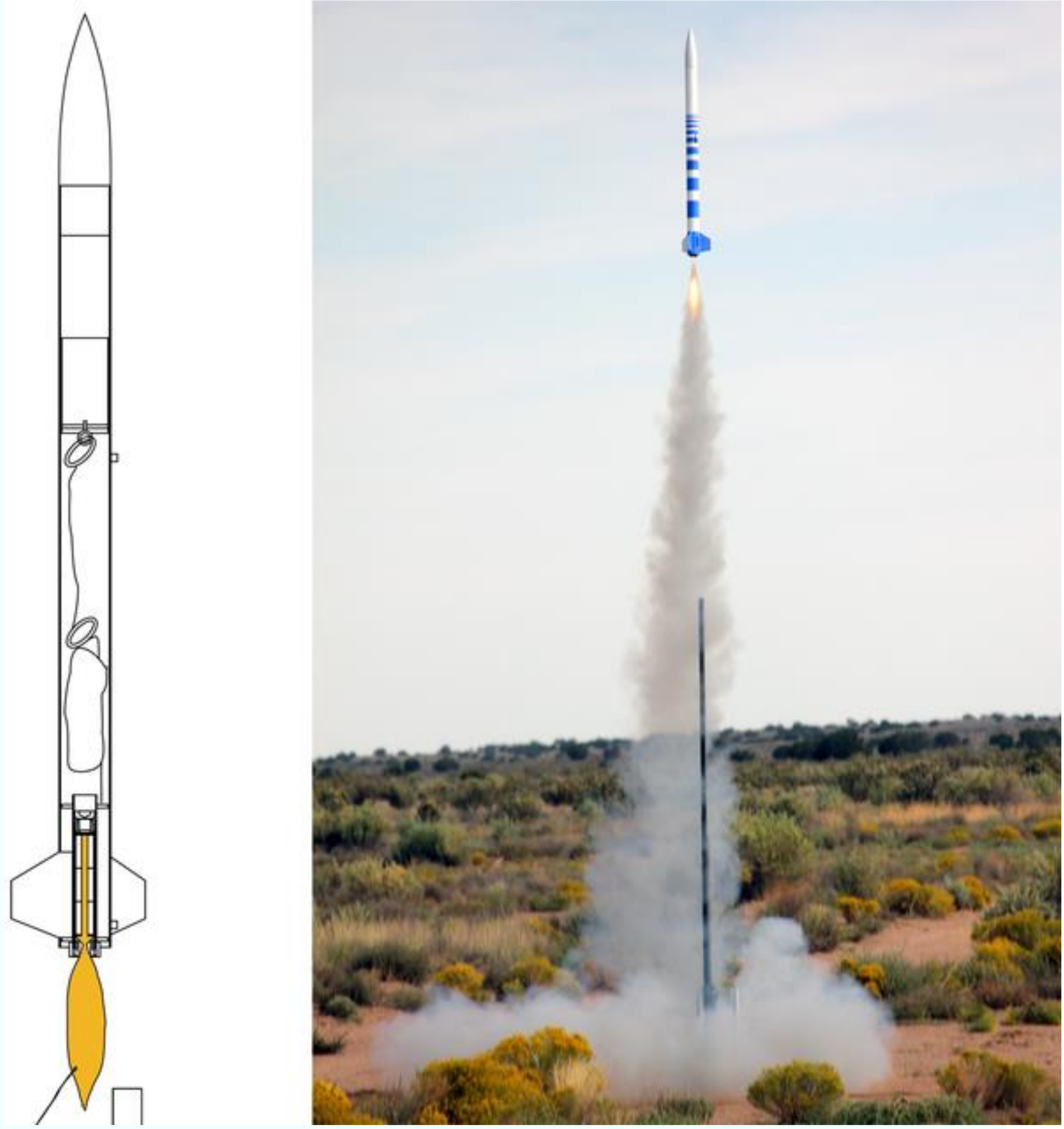


Figure 1-10. As the motor fires, the igniter falls out. By the time the rocket reaches the end of the launch rail, it is traveling fast enough for the fins to provide guidance.

It doesn’t take long for the rocket fuel to completely burn out. This happens about 1.5 seconds into the flight. The rocket is only 568 feet in the air at this point, but it is traveling at about 382 mph.

The first portion of the flight is over. With the ammonium perchlorate fuel burned out, the motor’s smoke charge finally becomes visible. Actually, the smoke charge started about the same time as the rocket fuel, but its effect was swamped until the ammonium perchlorate burned out. The smoke charge burns much more slowly than the ammonium perchlorate, and doesn’t provide any significant thrust. It does create a smoke trail, though, making it easier to see the rocket as it coasts up to its maximum altitude, the apogee. You can barely see Callisto in Figure 1-11, but the smoke trail is clear.

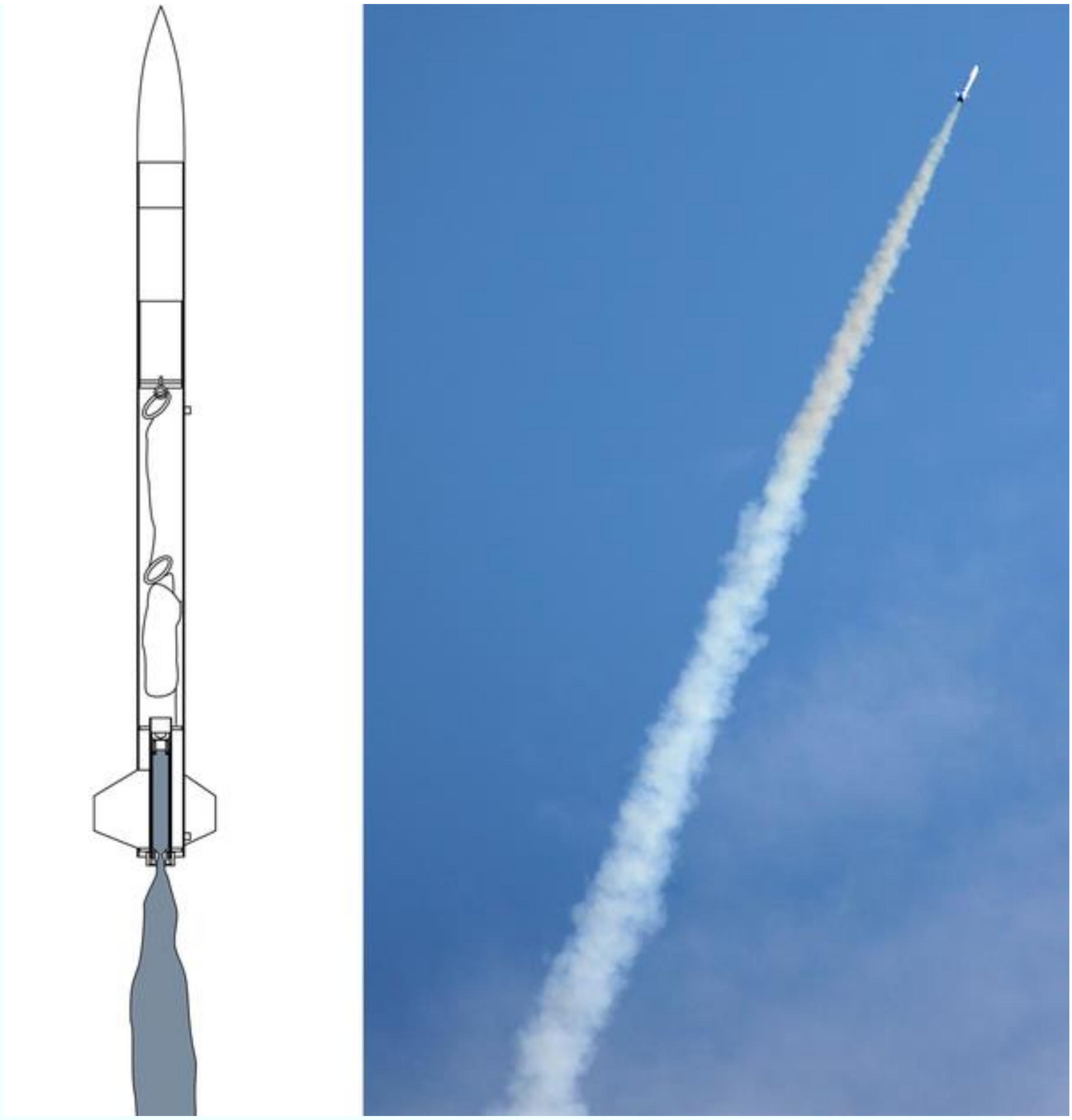


Figure 1-11. The smoke delay starts to burn after the ammonium perchlorate fuel is exhausted. This gives the rocket time to coast to apogee, and makes it easier to see the flight.

The smoke charge burns for 10 seconds. That’s about two seconds longer than the ideal time, so the rocket has tipped over and started its descent, but it is still traveling pretty slowly as the smoke charge burns out. The motor has one last section, the ejection charge, which fires as soon as the smoke delay stops. This is a small explosion, akin to a small firecracker, that blows the parachute out. The recovery blanket sits between the hot gases of the ejection charge and the nylon parachute, protecting it from being scorched.

The 36” parachute gives Callisto a nice, slow descent. It only takes Callisto about 9.5 seconds to get to apogee, but it is 2.5 minutes before Callisto gently lands. The nylon parachute you see in Figure 1-12 brings Callisto in for a nice soft landing.

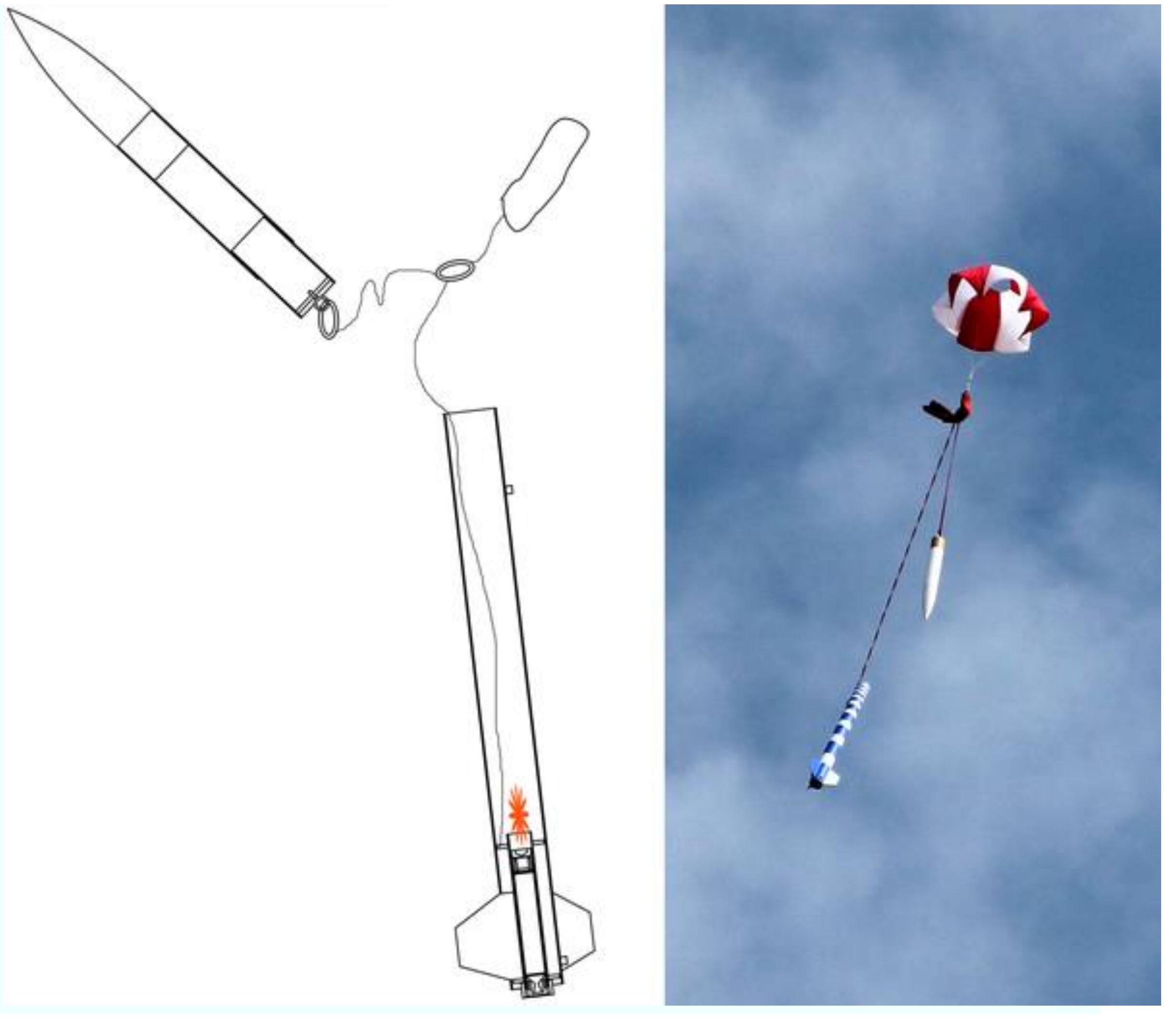


Figure 1-12. The ejection charge fires when the smoke delay is complete. It pushes the parachute and recovery blanket out. The parachute deploys for a gentle return to earth.

Now that you have an idea of what the rocket will do, let’s build it! Chapters 2 through 5 walk you through the process of building and flying Callisto, including getting your Level 1 certification.

Chapter 2. The Level 1 Rocket

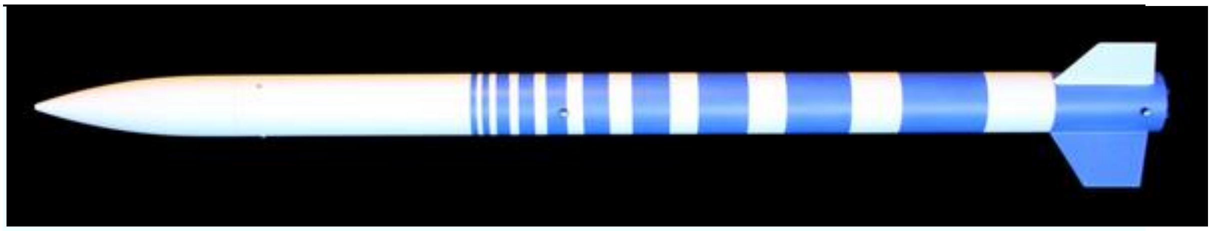


Figure 2-1. Callisto is a great Level 1 rocket that can also fly on mid-power motors.

Our first rocket is named Callisto, after one of the Galilean moons of Jupiter. Callisto (shown in Figure 2-1) is an easy, inexpensive rocket to build and fly. It's both a mid-power rocket and a high-power rocket, since it flies well on F through H motors. This is the only rocket in this book that you can fly on the recommended motors without a Class 2 FAA clearance, so it may end up being one of your most frequently flown rockets!

This is the first chapter in the book where we actually build a rocket, so we're going to go into a lot more detail here than in any of the other chapters. In addition to building the rocket, we'll also take a look at various tools and techniques you will use on all of the high-power rockets you build. We'll begin by designing the rocket in OpenRocket, a free rocket simulator. This is an important step for any high-power rocket, for reasons we'll discuss as we look at OpenRocket. Once we have a solid design, we'll take a very detailed look at the various parts, tools, and materials we'll use to actually build the rocket. As we build the rocket, we'll still take things slowly, discussing all of the techniques used for rocket construction. In Chapter 4, we'll start walking through the process of flying this rocket to get your Level 1 certification.

Don't skip this chapter! Even if you decide not to build this rocket, you should read this chapter carefully, because all of the other construction chapters assume you have read and understand the material covered here. You will no doubt refer back to this chapter many times as you build rockets from later chapters. Those chapters will tell you to perform some basic technique, such as filleting fins, assuming you already know how to do it. The details are in this chapter, so it's important that you review it thoroughly.

Should You Build This Rocket?

There are a lot of rockets in this book, and you probably aren't going to build and fly all of them. Some may not interest you, some may be difficult to fly with your local flying restrictions, and some may just be too expensive. There are also kits and other alternatives to consider. So, should you build this one? Let's take a look at some of the things you might consider as you make that choice.

One Rocket for Level 1 and 2?

One good way to get started in high-power rocketry is to go for your Level 2 certification, then decide how interested you are in continuing. The Level 2 certification is far enough along that you learn all of the basics of high-power rocketry. If you want to get to that point with a minimum of time and expense, one good technique is to build a single rocket that can fly on both a Level 1 motor and a Level 2 motor, then fly it twice, once for each certification. If that's your plan, you should skip this rocket. Don't skip the chapter—you need some of the information in this chapter to build the Level 2 rocket successfully—but you can skip building the rocket itself.

On the other hand, the Level 2 rocket from this book is similar to most Level 2 rockets in one important way: it's too big to fly on mid-power motors. You can learn a lot with mid-power motors, and they are much cheaper than their higher-power counterparts. You can also fly mid-power motors without a Class 2 FAA clearance, and some can be flown with no clearance at all, so you can slip off by yourself for some flights without the hassle of getting an FAA Class 2 clearance, or waiting until your local rocket club gets one for you.

Another consideration is your experience level. If you're a long-time model rocketeer who is venturing into high-power rocketry for the first time, this rocket is not all that dissimilar from larger low-power rockets you may have built, so you might not need the experience. If you've never built a rocket of any kind before, or if you only built them a few times as a kid, Callisto is a great rocket for (re)learning basic techniques. Your mistakes will also be less expensive and safer to recover from!

What’s in a Name?

When you complete your flight card, one of the things you will need to fill in is the name of your rocket. What should it be?

Looking around at full-size rockets, you see a wide variety of names, from whimsical to serious. The US space program has tended toward mythological names like Mercury, Gemini, Apollo, and Orion. The Space Shuttle names tended to derive from ships of old, with two of the shuttles, *Endeavour* and *Discovery*, being named for Captain Cook’s vessels of scientific exploration. In our case, all of the rockets in this book carry the name of a moon in our solar system. Perhaps it gives us something to shoot for!

Callisto is one of the four Galilean moons of Jupiter. Their discovery in 1610 gave Galileo a model of a system that helped convince him the Earth and other planets rotated around the Sun. To put it mildly, this was not a popular idea at the time.

The third largest moon in the solar system, Callisto is just a few tens of kilometers smaller than the planet Mercury. It’s made of a mixture of rock and ice, and possibly has a subsurface ocean. Unlike Europa, though, it orbits outside of most of the protective magnetosphere of Jupiter, so although it is possible there is life on Callisto, it’s unlikely.

Callisto is named after a nymph from Greek mythology associated with the goddess of the hunt.

Cost per Flight

A lot of the things we’re going to try with the Level 2 rocket could also be done with Callisto. You could easily adapt this design for electronic deployment or dual deployment. It’s true that Callisto doesn’t actually need electronic deployment or dual deployment like the larger rockets, but you can use it as a platform to learn how to use altimeters for dual deployment, where a flight computer controls ejection of a single parachute or multiple parachutes.

Your flights will cost a lot less, at about $20 per flight for an H motor as opposed to $50 per flight for a J motor. To be fair, you can fly the Level 2 rockets from Chapter 6 with an H motor, too, but then, you can also fly Callisto with an even less expensive F motor.

Then there are crashes. Let’s face it, not all of your flights are going to be successful. You’re going to repair or replace a few rockets. Callisto costs less to build and repair than the larger rockets from later in the book. It’s a great learning platform.

Rocket Kits

Maybe you’ve decided to build a Level 1 rocket like this one, but you do not want to hunt down all of the parts for this specific rocket. Kits are a great alternative, as they come with almost everything you need to build the rocket. Add paint, glue, and perhaps a motor retainer and some rail buttons, and you have everything you need. You should still read this chapter for information about tools, supplies like glue, and techniques needed to build a rocket, but kits are a very good alternative to Callisto. They might even be available locally!

One thing to keep in mind with kits, though, is that you are still likely to need a few additional parts. Kits in this size rarely come with rail buttons, which are used to hold the rocket on the launch pad. They sometimes come with launch lugs, an alternative way to hold the rocket on the pad, but most club launchers for high-power rockets use launch rails, not launch rods. We’ll cover launch lugs and rail buttons later in the chapter. For now, just be sure you check the kit to make sure it has what you need.

Kits also rarely come with a motor retainer, which is used to hold the motor in place during flight. There are a lot of really good alternatives for motor retention, and we’ll cover the major ones later in the chapter. Check the parts list for any potential kit carefully. Buy a motor retainer separately if the kit does not come with one.

Let’s take a quick look at a few kits you might want to consider. All of the companies mentioned in this book produce really great kits, so if you decide on a kit, it’s really a matter of choosing one that fits your budget and desires.

Estes Industries is a well-known giant in low-power rocketry. They also make a nice line of rockets designed for mid-power motors, and they sell E, F, and G motors to power these rockets. What a lot of people may not realize is that these rockets are perfectly capable of flying with high-power H motors with a little modification. It’s best to follow the construction techniques from this chapter when building these rockets, especially when attaching the fins, but the Estes Pro Series rockets fly just fine on H motors; I know because I’ve flown their Nike Smoke and Leviathan on H motors. If you add a plywood bulkhead and eye bolt from the hardware store, you can convert their Partizon into a rocket that is very similar to Callisto.

Madcow Rocketry has an extensive line of kits. Their DX3 is almost a dead ringer for the Callisto. Sure, the fins have a different shape, and the rocket is a bit shorter, but the parts and materials are very similar. It comes with launch lugs. You will need to add rail buttons and a motor retainer to build the kit as Callisto is described in this chapter.

While there are currently no other kits that are a close match for Callisto, there are a lot of other kits suitable for your Level 1 flight. Some are scale models, while others are larger or smaller than Callisto. The construction techniques in this chapter will work fine with all of them. Take a look at the vendors listed in Appendix A. Poke around their websites before making a final selection.

Designing High-Power Rockets

If you’ve flown low-power rockets, you’re likely already accustomed to buying a rocket kit and loading it with the motors listed on the package. If you built your own design, you may have just compared it to a kit and used motors that seemed “about right.” That works OK most of the time, although there are occasional mishaps. I’ve seen rockets bury themselves in the grass before the ejection charge fired, and watched parachutes shred from the force of the wind when an ejection charge fired early. While it’s not good to mismatch rockets and motors, it’s generally a mistake that you can recover from without huge consequences.

Things change with high-power rocketry. First, there are literally hundreds of motor and ejection charge combinations to choose from. Rockets that look nearly identical on the launch pad can have dramatically different weights, even without considering the vast number of payloads they might carry. Mistakes are both more expensive (a high-power rocket can easily cost 20 times as much to build as a low-power rocket) and more dangerous. Instead of thin, collapsible paper tubes, balsa wood fins, and balsa or thin plastic nose cones, high-power rockets like Callisto are built with thick, sturdy paper tubes, thick plastic nose cones, and plywood fins. The rockets we’ll build later in the book often have stronger body tubes, made of plastic, fiberglass, or even carbon fiber. The nose cones are frequently metal-tipped fiberglass or carbon fiber, and the fins are thick plywood, fiberglass, or carbon fiber. These are not the light, safe rockets you see flying at parks. High-power rockets are potentially lethal missiles that deserve a great deal of respect and care.

So, before you take a strong, inflexible rocket weighing several pounds and fling it into the air, you need to have a very good idea of how it will fly. You also need to be certain that the motor you choose will be both powerful enough to lift the rocket and light enough to keep the rocket stable, and has an ejection charge that will eject the parachute while the rocket is traveling slowly, so the chute won’t rip itself apart from the air pressure.

You can ensure all these things by using a rocket simulator. You should simulate every mid- and high-power rocket you build. A separate simulation should be conducted for any new motor you want to use, and also for any payload change that varies the weight or weight distribution in the rocket.

Choosing a Simulator

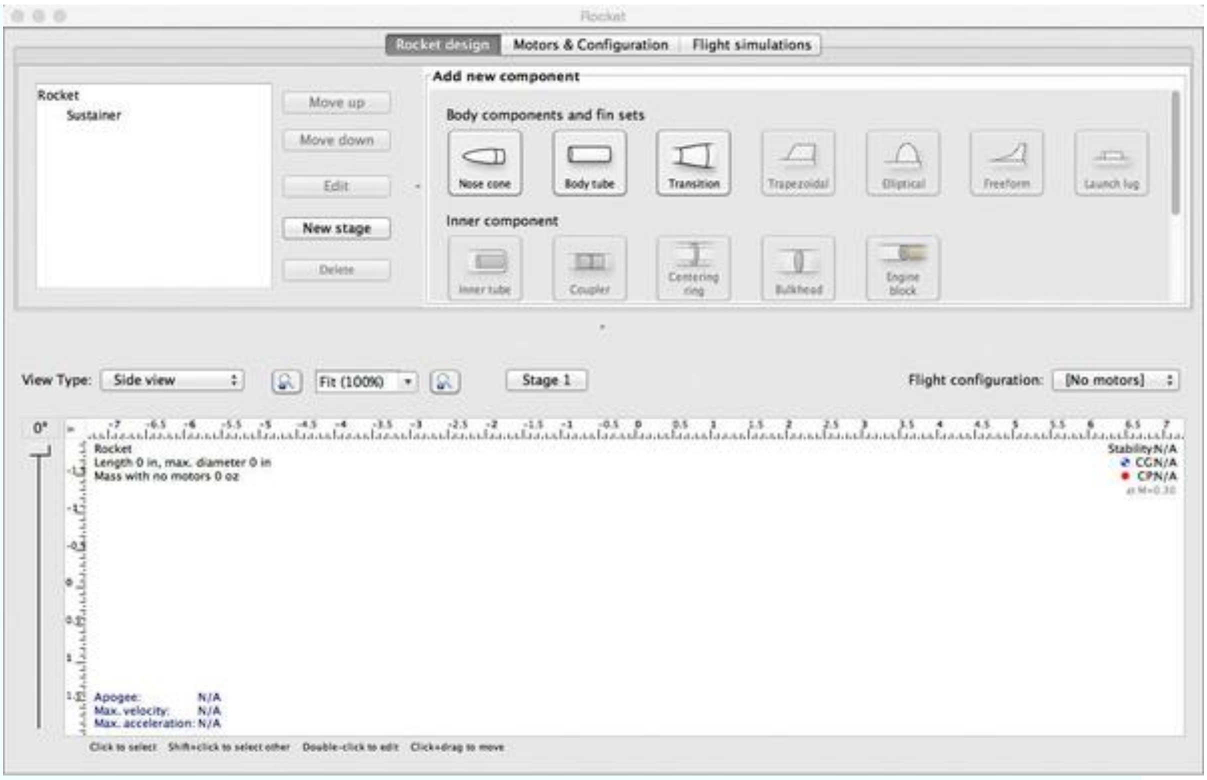
There are a number of good rocket simulators you can use. One of the most popular is called RockSim. It’s available from Apogee Components. I’ve used it on many designs, as have many members of my local rocket club. As I write this, the full version is about $125. There is also a professional version that adds options that are useful for very high-altitude flights, although at $1,000, the price is sky-high too. You don’t need the professional version for anything in this book, and you may not need to pay the retail price for the full version, either—there are student and Team America Rocketry Challenge (TARC) discounts, as well as a free 30-day trial. I highly encourage you to go to the Apogee website to download the free trial and give RockSim a try.

This book will use another rocket simulator called OpenRocket, but it’s easy enough to follow along with RockSim if you decide to use it instead of OpenRocket. OpenRocket is a rocket simulator originally created by Sampo Niskanen for his master’s thesis at the Helsinki University of Technology. It is currently an open source software project, which means you can download and use it for free. In fact, if you are so inclined, you can even download the source code and make changes. OpenRocket simulates the rockets in this book just as well as RockSim, although RockSim has some specialized features for things like tube fins that OpenRocket will not handle. Both are fine simulators, and I’ve used both to simulate flights so I could get two simulated opinions about a rocket. We’ll use OpenRocket in the book because it is free. You can get a copy at the OpenRocket website.

Rocket simulation is pretty active at the moment. There are a lot of other rocket simulators out there, many for highly specialized tasks like parachute selection or fluid flow. Some are no more than useful spreadsheets, while others are very complex physics simulations. By all means, do a web search for “rocket simulators” to see what might have come out since this book was published.

Getting Started with OpenRocket

If you haven’t already done so, go to the OpenRocket website and download a copy of the simulator. Follow the installation instructions to get it running on your computer (you need to have Java installed and running). When you run OpenRocket, you’ll see an empty design screen similar to the one in Figure 2-2. This screenshot is from a Macintosh running Yosemite; the screen may look a little different if you are running on Windows or a Linux system, but the content will be the same.



View Type: Side view

Fit (100%)

Flight configuration: [No motors]

Rocket
Length 0 in, max. diameter 0 in
Mass with no motors 0 oz

Stability:N/A
CG:N/A
CP:N/A

Apogee: N/A
Max. velocity: N/A
Max. acceleration: N/A

Figure 2-2. The starting window for OpenRocket.

Right across the top of the window are three tabs that capture what a rocket simulator is all about. The first tab, which is the one that is open in the screenshot shown here, is “Rocket design.” This is where you will create the design for Callisto. As you design the rocket, you’ll see basic information about what you’re doing and the overall layout in the bottom portion of the window.

The next tab is “Motors & Configuration.” This is where you will select a motor for a rocket flight and indicate what ejection charge to use, when motors on other stages will fire, and so forth.

The last tab is “Flight simulation.” With a design and configuration in hand, this is where you’ll be able to accurately simulate the flight of your rocket.

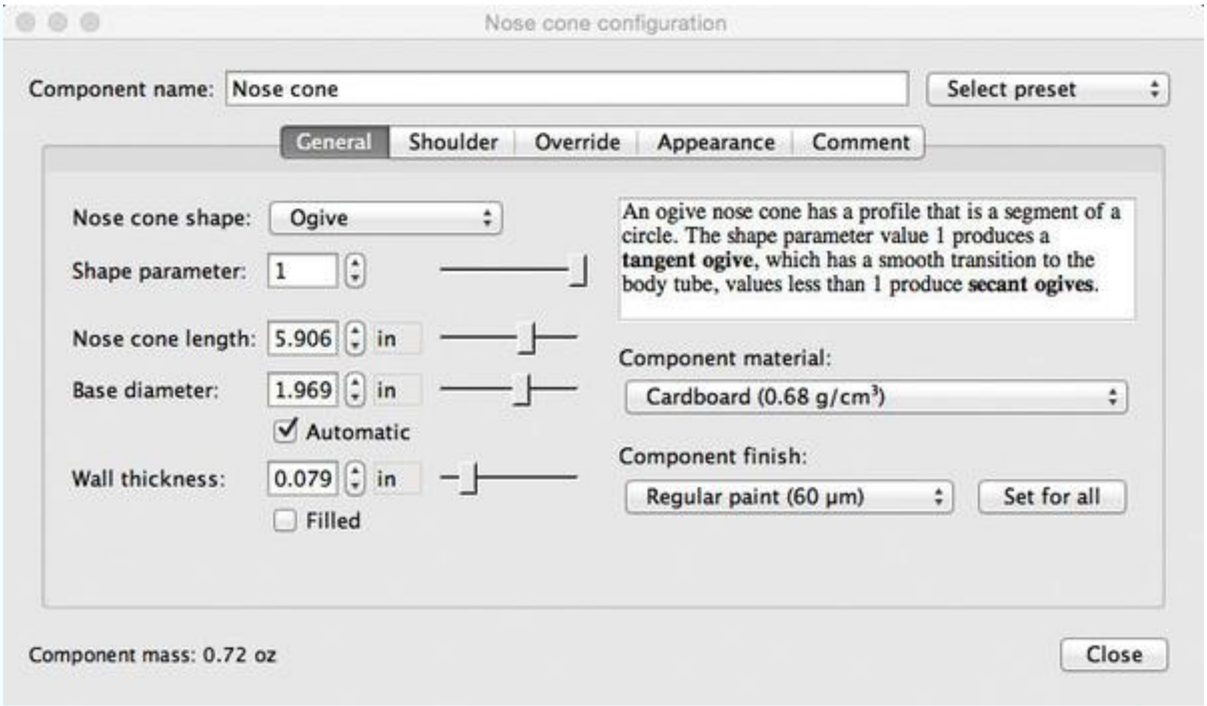
But we’re getting ahead of ourselves! Let’s go through the process of designing Callisto.

TIP

The sizes of most of the parts used in Callisto are listed in inches on the manufacturer’s website, so I’ll use inches as we design the rocket. You can work in whatever units you are most comfortable with, or even switch between them.

Use the OpenRocket preferences dialog to change the overall units to whatever you would like to use. Naturally enough, they default to metric units. You can also change the units for an individual measurement by clicking on the units next to the value and selecting the units you would like to use.

There is a pane labeled “Add new component” at the top right of the window in Figure 2-2. The first component is the nose cone, and that’s a good place to start. While you can easily rearrange components or insert a new one between existing components, OpenRocket normally adds components on the right, just like a word processor adds new characters on the right as you type. The rocket is drawn pointing to the left, so the nose cone is the proper place to start. Click on “Nose cone.” A dialog like the one in Figure 2-3 opens.



Component name: Nose cone

Nose cone shape: Ogive

Shape parameter: 1

Nose cone length: 5.906 in

Base diameter: 1.969 in

☑ Automatic

Wall thickness: 0.079 in

☐ Filled

An ogive nose cone has a profile that is a segment of a circle. The shape parameter value 1 produces a **tangent ogive**, which has a smooth transition to the body tube, values less than 1 produce **secant ogives**.

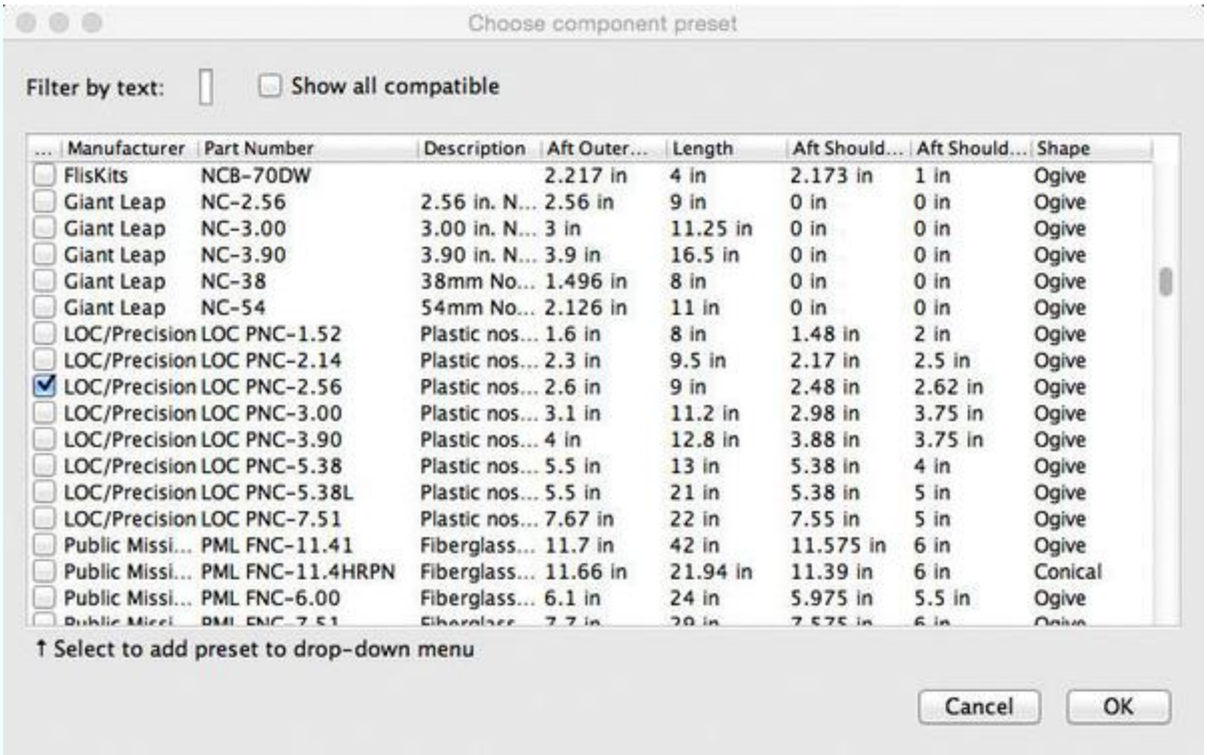
Component material: Cardboard (0.68 g/cm^3)

Component finish: Regular paint (60 μm)

Component mass: 0.72 oz

Figure 2-3. Click on “Nose cone” in the “Add new component” pane to open this dialog.

There are a lot of tabs and options in this dialog that will let you design pretty much any nose cone you have ever seen on a rocket, and a few that have never been tried. You could go to the manufacturer’s website, look at the specifications for a nose cone you want to use, make a few educated guesses about anything that’s not listed, and create the nose cone from scratch. I’ve done that many times, and it works pretty well. There is a better way, though. Click on the “Select preset” drop-down menu and select “Select preset”; a new dialog like the one in Figure 2-4 will open. Scroll down until you see LOC/Precision for the manufacturer, then select LOC PNC-2.56 by clicking on the checkbox at the start of the line.



...	Manufacturer	Part Number	Description	Aft Outer...	Length	Aft Should...	Aft Should...	Shape
☐	FlisKits	NCB-70DW		2.217 in	4 in	2.173 in	1 in	Ogive
☐	Giant Leap	NC-2.56	2.56 in. N...	2.56 in	9 in	0 in	0 in	Ogive
☐	Giant Leap	NC-3.00	3.00 in. N...	3 in	11.25 in	0 in	0 in	Ogive
☐	Giant Leap	NC-3.90	3.90 in. N...	3.9 in	16.5 in	0 in	0 in	Ogive
☐	Giant Leap	NC-38	38mm No...	1.496 in	8 in	0 in	0 in	Ogive
☐	Giant Leap	NC-54	54mm No...	2.126 in	11 in	0 in	0 in	Ogive
☐	LOC/Precision	LOC PNC-1.52	Plastic nos...	1.6 in	8 in	1.48 in	2 in	Ogive
☐	LOC/Precision	LOC PNC-2.14	Plastic nos...	2.3 in	9.5 in	2.17 in	2.5 in	Ogive
☑	LOC/Precision	LOC PNC-2.56	Plastic nos...	2.6 in	9 in	2.48 in	2.62 in	Ogive
☐	LOC/Precision	LOC PNC-3.00	Plastic nos...	3.1 in	11.2 in	2.98 in	3.75 in	Ogive
☐	LOC/Precision	LOC PNC-3.90	Plastic nos...	4 in	12.8 in	3.88 in	3.75 in	Ogive
☐	LOC/Precision	LOC PNC-5.38	Plastic nos...	5.5 in	13 in	5.38 in	4 in	Ogive
☐	LOC/Precision	LOC PNC-5.38L	Plastic nos...	5.5 in	21 in	5.38 in	5 in	Ogive
☐	LOC/Precision	LOC PNC-7.51	Plastic nos...	7.67 in	22 in	7.55 in	5 in	Ogive
☐	Public Missi...	PML FNC-11.41	Fiberglass...	11.7 in	42 in	11.575 in	6 in	Ogive
☐	Public Missi...	PML FNC-11.4HRPN	Fiberglass...	11.66 in	21.94 in	11.39 in	6 in	Conical
☐	Public Missi...	PML FNC-6.00	Fiberglass...	6.1 in	24 in	5.975 in	5.5 in	Ogive

Figure 2-4. Click on “Select preset,” then choose “Select preset” to open this dialog. Select LOC PNC-2.56, and then click OK. Pull down “Select preset” again and select LOC PNC-2.56, then click Close.

Once you’ve selected the nose cone, click OK. Nothing changes, yet. Pull down the “Select preset” drop-down menu again, though, and you will see that LOC PNC-2.56 has been added to the list of nose cones.

Select it, and you will see all of the appropriate values filled in for this nose cone.

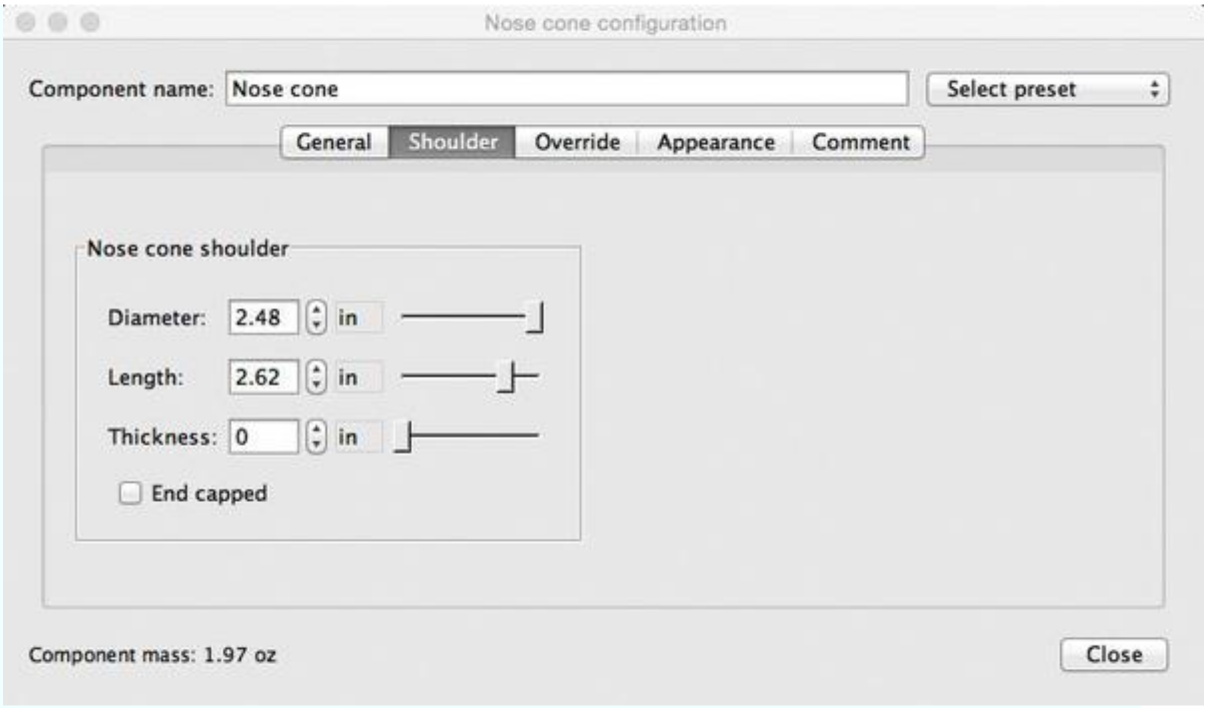
TIP

You can add an item to the presets by selecting the appropriate checkbox and clicking OK. It’s a good idea to do this for commonly used parts so they can quickly be found without searching the database each time. For parts you don’t expect to use frequently, just select the line itself (not the checkbox) and click OK. This adds the part without adding it to the presets.

Take a moment to flip between the various tabs (Shoulder, Override, and Appearance) to see how this nose cone is specified. This is an important step for two reasons. The first is that you’re learning how to use OpenRocket, and flipping through the options shows you what is available and how the various fields are filled in for a real nose cone. The other reason is that you are responsible for your designs and flights. Simulators are good, but they are not perfect. You need to check all of the values to make sure they make sense to you. If they don’t, ask for help from an experienced rocket scientist before making a change—after all, you might be changing something that looks odd because of your experience level, but is really correct!

When you feel familiar with the specifications for the nose cone, click Close. The nose cone appeared in the “Rocket design” window as soon as you selected it, but you may not have seen the image change if the dialogs were covering the window. At this point, though, you should see a nose cone that is 9” long and 2.56” in diameter. The *shoulder*—the part that will slide into the body tube of the rocket—is 2.62” long and a little narrower than the base of the nose cone.

There are a couple of minor problems here. Can you spot what’s wrong? Double-click on the nose cone in either the parts list at the top left of the window or the drawing at the bottom, and then click on the Shoulder tab. You will see a dialog like the one in Figure 2-5. The first issue is that the thickness is 0. This is the wall thickness of the plastic in the shoulder section of the nose cone, and it is obviously not zero. For now, enter 0.125, the same value you see for the thickness of the nose cone in the General tab.



Component name: Nose cone

Diameter: 2.48 in

Length: 2.62 in

Thickness: 0 in

☐ End capped

Component mass: 1.97 oz

Figure 2-5. The Shoulder tab shows a shoulder with no thickness and no end cap.

The other problem is that the actual nose cone has an *end cap*—in other words, there is plastic across the bottom closing off the nose cone. Not all nose cones have an end cap. It’s a detail that you may not pick up on until your order arrives and you look at the physical nose cone, but it can be important. Click on the “End capped” checkbox.

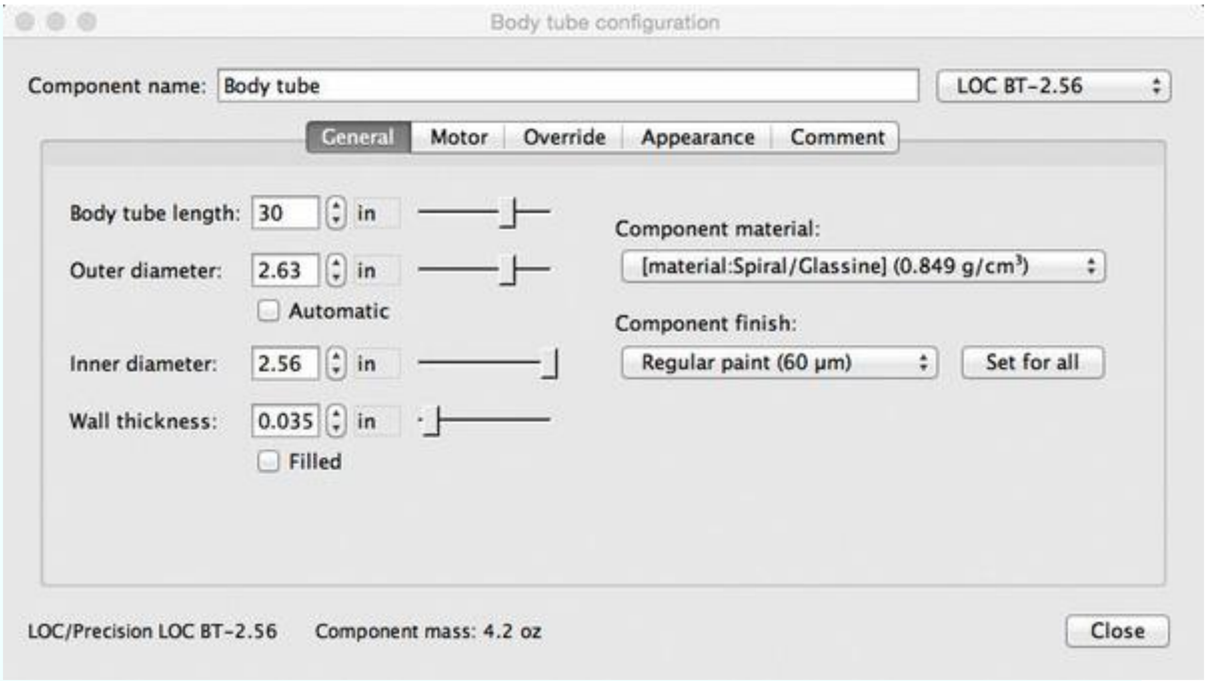
When you do this, you might notice one of the symbols in the “Rocket design” window shifting to the right. The circle with the blue and white checkered pattern indicates the *center of gravity*, which is the balance point of the component. It will shift back from about 5.5” to about 7.3” as you adjust the shoulder.

While a small change in one component probably won’t have much of an impact on the overall design, we should still be as precise as possible. The reason is that the center of gravity and *center of pressure* tell us if the rocket is stable. The center of pressure is marked with the red circle surrounding the red disk, and is the point at which the rocket will be balanced in the wind. If our simulation is off, we could end up with a rocket that looks stable on the computer, but is not stable in flight. This change is worth making.

All of these changes have created another problem, though. According to the manufacturer, the nose cone will weigh 3 ounces (oz), which is what the weight was when we started. Our changes have added 1.52 oz to the weight. We need to adjust the wall thickness so that the weight matches what was specified by the manufacturer. You can play with the numbers to iterate to the correct value, but I'll give you a hint: it's 0.0807". Don't forget to adjust both the nose cone and the shoulder.

So, are these the correct values? Nope. First, the computer model of the nose cone is not entirely accurate. If you look ahead in the chapter, you can see that there is a cone-shaped area at the base of the shoulder, as well as a much thinner cylindrical protuberance. Paint adds a bit of weight. There are variations in the manufacturing process. The actual finished nose cone from my version of Callisto weighs 3.75 oz and has a center of gravity 6.6" from the tip of the nose cone. Yours will be different. These differences will add up, but they are rarely important. Still, we'll take care of them after the rocket is built, when we tune our simulation.

Wow—that's a lot of work for a nose cone! It goes a lot faster as you learn the program, though. Let's continue by building the payload bay for Callisto. In the "Add new component" pane, click on "Body tube." Using the same pattern as for the nose cone, click on the "Select preset" drop-down menu at the top right of the dialog, then seek out and select LOC BT-2.56 and click OK. Select this body tube from the drop-down menu and you will have a dialog like the one in Figure 2-6.


Body tube configuration

Component name: Body tube

LOC BT-2.56

Body tube length: 30 in

Outer diameter: 2.63 in

☐ Automatic

Inner diameter: 2.56 in

Wall thickness: 0.035 in

☐ Filled

Component material: [material:Spiral/Glassine] (0.849 g/cm³)

Component finish: Regular paint (60 μm)

LOC/Precision LOC BT-2.56

Component mass: 4.2 oz

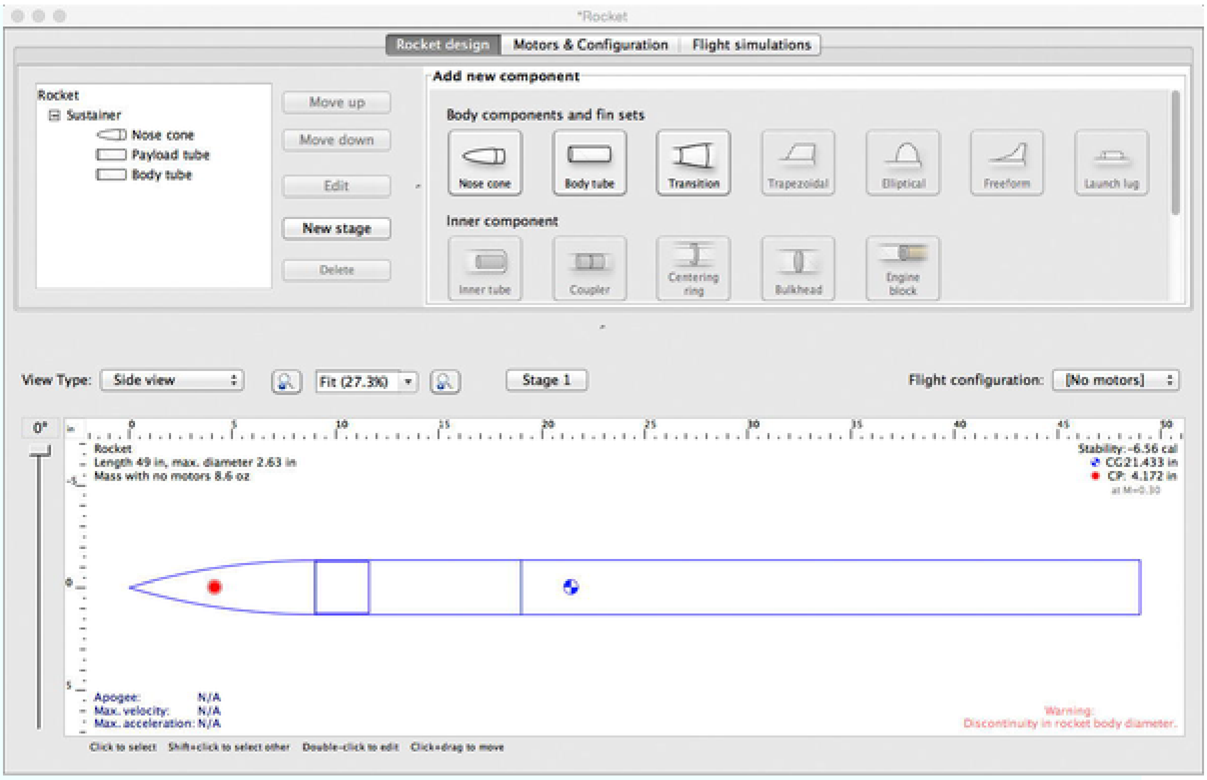
Figure 2-6. Select LOC BT-2.56 for the body tube for the payload bay.

This is pretty close to what we want. The main problem is that the body tube is way too long. Change “Body tube length” from 30 to 10. We’re also going to end up with two body tubes, and that might get confusing. Let’s update the name of this one by changing “Component name” from “Body tube” to “Payload tube.”

Follow the same pattern to add another body tube. This is the main body tube for the rocket, and it really will be 30” long. The original component name of “Body tube” works pretty well for this part, too.

At this point, the rocket looks like what you see in Figure 2-7. It’s starting to look a little more like the picture at the start of the chapter. Our rocket still needs fins, and there are a lot of internal parts to add, but the general outline looks right.

There is a problem, though. There is a warning at the bottom right of the window that says, “Discontinuity in rocket body diameter.” This is telling us that the various body tubes and nose cones are not all the same size. That may be reality for some rocket designs, but in this case it is not.



View Type: Side view

Fit (27.3%)

Flight configuration: [No motors]

Rocket
Length 49 in, max. diameter 2.63 in
Mass with no motors 8.6 oz

Stability: -6.56 cal
CG:21.433 in
CP: 4.172 in
at M=0.30

Apogee: N/A
Max. velocity: N/A
Max. acceleration: N/A

Warning:
Discontinuity in rocket body diameter.

Figure 2-7. Here's our rocket so far. There is a warning we need to take care of.

TIP

You can edit a component by double-clicking on the part on the rocket design, but you must click on one of the lines that form the component, not in the middle.

Double-click on the various components, either in the list at the top left of the window or in the image of the rocket. Check the various diameters. The source of the problem is that the diameter for the nose cone is 2.6", but the diameter for the body tubes is 2.63". Checking with the manufacturer's website, we see that the outside diameter of the body tubes should be 2.63", which is what we have. The outside diameter of the nose cone is not listed. Change the nose cone to have a diameter of 2.63". The warning should go away. You might have noticed this added a tiny amount of weight to the nose cone. If you would like to get it down to an even 3 oz again, change the wall thickness to 0.08" on both the General and Shoulder tabs—but as we've already seen, the actual weight of the real nose cone might vary more than this small difference. After all, my real nose cone weighs 3.75 oz.

WARNING

You have seen this twice, now. While the database of components is very useful, it does have mistakes. Parts change from time to time, too. You must check everything you grab from the database carefully to make sure it matches reality. This is something I’ve seen in RockSim, too. The database is huge, and there are minor errors on occasion.

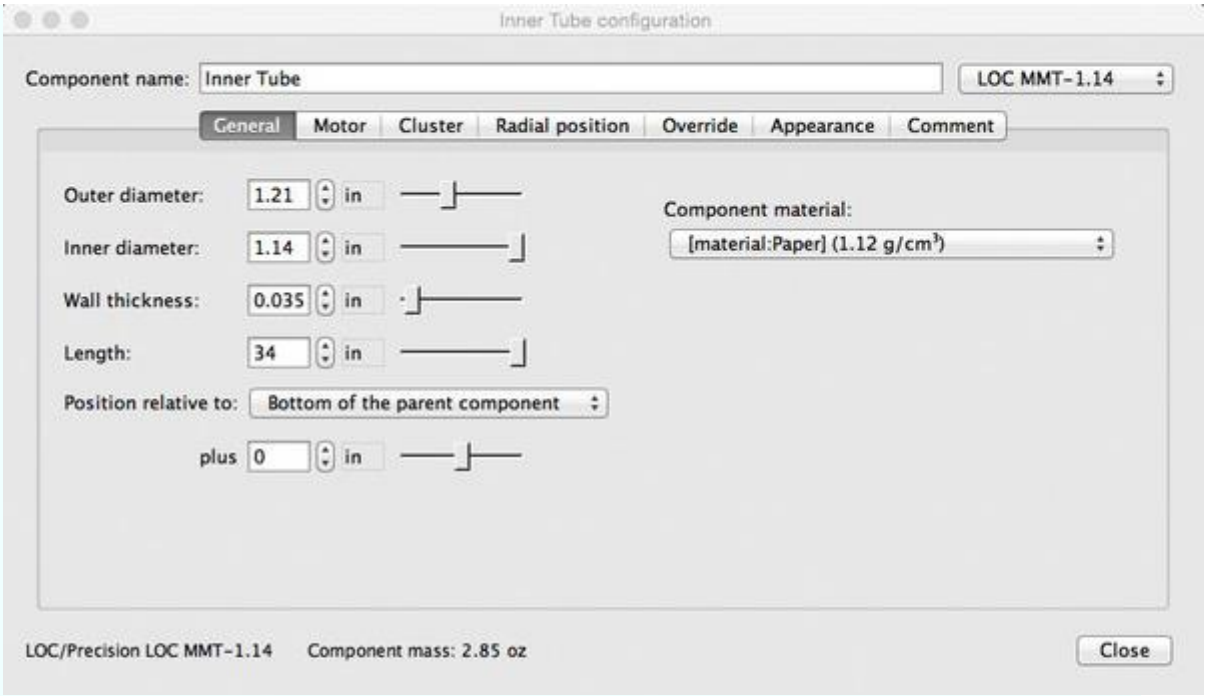
These errors rarely cause serious problems, but it’s important to pay attention and correct them, as doing so reduces the chance of a flight incident.

Also, to be fair, it’s not common to find two errors this close together. It does help to make the point about checking the computer’s database and results to make sure they make sense, though.

The next step is to add the motor mount. This is a second tube that fits inside the booster’s body tube. Like most Level 1 rockets, this motor mount is sized for 29 mm–diameter motors.

Select the body tube by clicking on either the part in the parts list or the outline of the body tube in the drawing of the rocket. Click on “Inner tube” to add the motor mount. Select LOC MMT-1.14 from the database. Your dialog should look like Figure 2-8.

Start by changing the name of the component from “Inner Tube” to “Motor Tube.” It’s also way too long, longer than the booster itself. Shorten the length from 34” to 8”.



Component name: Inner Tube

LOC MMT-1.14

Outer diameter: 1.21 in

Inner diameter: 1.14 in

Wall thickness: 0.035 in

Length: 34 in

Position relative to: Bottom of the parent component

plus 0 in

Component material: [material:Paper] (1.12 g/cm^3)

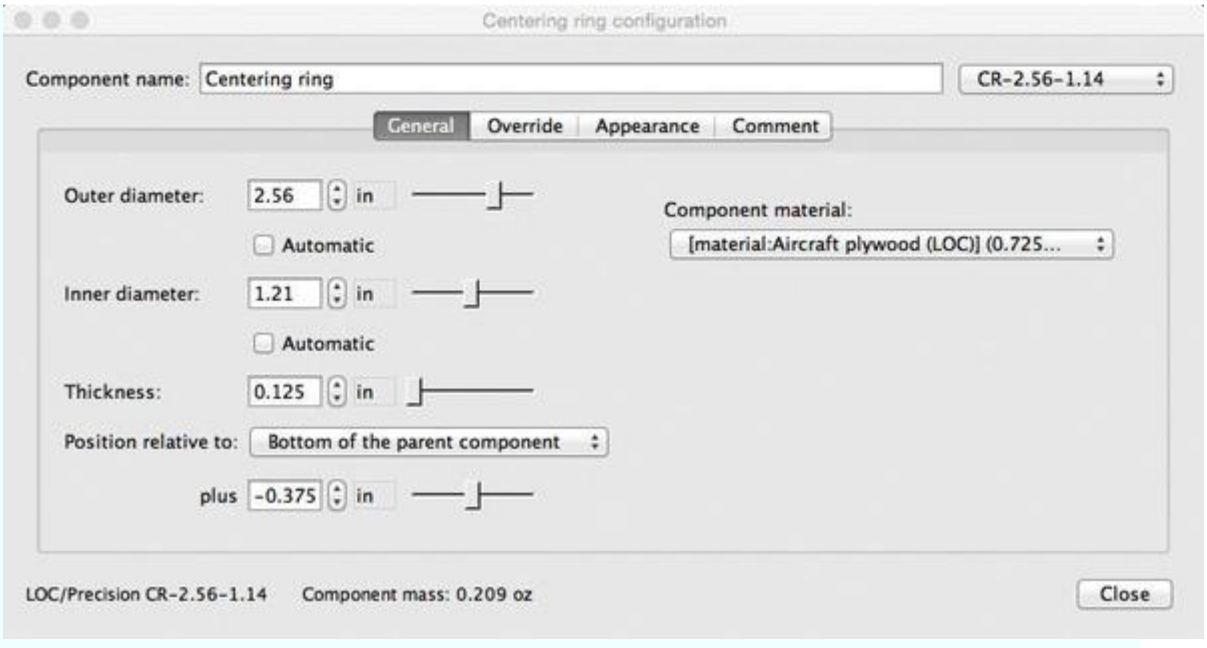
LOC/Precision LOC MMT-1.14 Component mass: 2.85 oz

Figure 2-8. The motor mount with the initial part selected.

While we don't need to change the values, it's worth noticing the "Position relative to" and "plus" settings. These set the position of the motor mount relative to the component that owns it—in this case, the main body tube. If you pull down the menu, you will see several choices for how to specify the position of the component. I usually set the position relative to the top or bottom of the owning component, but it's nice to have options. The value of the "plus" setting tells how far the component will be from the parent component.

Move to the Motor tab and check "This component is a motor mount." This tells the program we can load a motor into this tube. Change "Motor overhang" from 0" to 0.25"; this tells the program the motor will stick out the back a bit. None of the other settings need to be adjusted at this point, but go ahead and explore the rest of the tabs to familiarize yourself with the program.

That simulated motor tube is hanging inside the simulated body tube rather well, but in a real rocket we will need some way to physically hold it in place. We do that with centering rings. Select the body tube, then click on "Centering ring" to add the first of two centering rings. Select CR-2.56-1.14 from the database, and place it –0.375" from the base of the body tube. This leaves room for the fins we'll eventually add. The bottom of the fin will be 1/2" from the bottom of the body tube. We need to move the centering ring toward the aft end of the rocket by its thickness to leave room for the fin. Your dialog should look like Figure 2-9.



Component name: Centering ring

CR-2.56-1.14

Outer diameter: 2.56 in

☐ Automatic

Inner diameter: 1.21 in

☐ Automatic

Thickness: 0.125 in

Position relative to: Bottom of the parent component

plus -0.375 in

Component material: [material:Aircraft plywood (LOC)] (0.725...

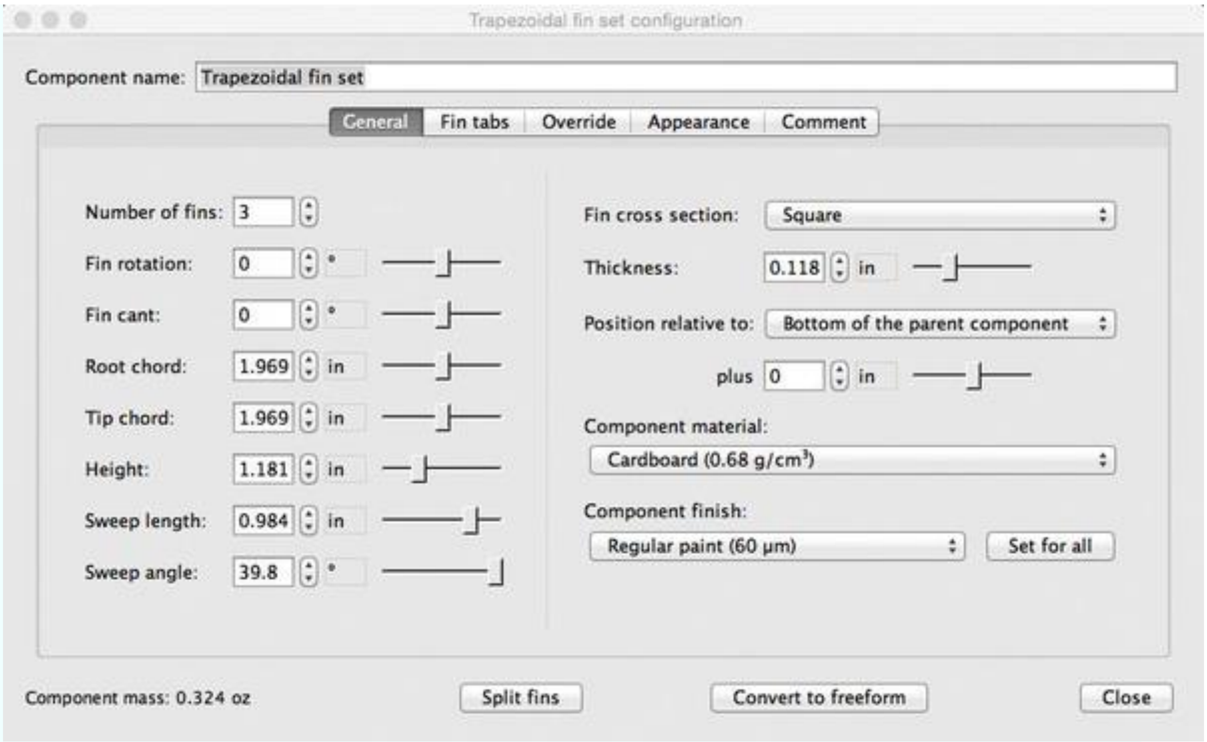
LOC/Precision CR-2.56-1.14   Component mass: 0.209 oz

Figure 2-9. Add a centering ring 3/8" from the base of the body tube.

Add a second centering ring –7.5" from the base of the component.

It's time for some fins! Select the body tube, and then click on "Trapezoidal." There are several other fin designs. If you don't like mine, you can certainly choose your own. We're going to cut them from plywood, so you can select just about any shape you want.

The default fins look pretty sad, don't they? Let's work through the various options to see how to create an appropriate set of fins. As you start, your dialog will look like Figure 2-10.



Component name: Trapezoidal fin set

Number of fins: 3
Fin rotation: 0 °
Fin cant: 0 °
Root chord: 1.969 in
Tip chord: 1.969 in
Height: 1.181 in
Sweep length: 0.984 in
Sweep angle: 39.8 °

Fin cross section: Square
Thickness: 0.118 in
Position relative to: Bottom of the parent component
plus 0 in
Component material: Cardboard (0.68 g/cm^3)
Component finish: Regular paint (60 μm)

Component mass: 0.324 oz

Figure 2-10. The default settings for trapezoidal fins.

There are a lot of terms in this dialog that may look unfamiliar. Figure 2-12 shows the various terms on a labeled fin.

Fin Shapes

You can use just about any fin shape you like as long as it has a generous length where it connects to the body tube and isn’t so oddly shaped that it is obviously week in spots. Just about anything that looks like it belongs on a rocket—and a lot of things that don’t—will work just fine.

Three of the most common fin shapes are shown in Figure 2-11. If you are curious, you can find a detailed discussion of fin aerodynamics in *Make: Rockets*. For now, there are a few general things to keep in mind when planning fins for a model rocket.

While swept fins are associated with speed, it turns out that they actually have higher drag at subsonic speeds. Even supersonic model rockets spend most of their time at subsonic speeds, so there is rarely any reason to sweep the fins on a model rocket—except that they really do look cool.

The most efficient fin shape at subsonic speeds is an oval. A trapezoid is almost as good, though, and it is also a lot easier to make. Most of my rockets end up with trapezoidal fins. In addition to being efficient and easy to make, they have another advantage in the rocky high desert areas where I typically fly. Swept fins have a relatively delicate point at the base of the fin, which is very easy to chip or break when landing on a hard surface. They are fine in grassy or sandy areas, but if you are flying in a place where a rocket is likely to land on a hard surface, trapezoidal fins survive landings better.

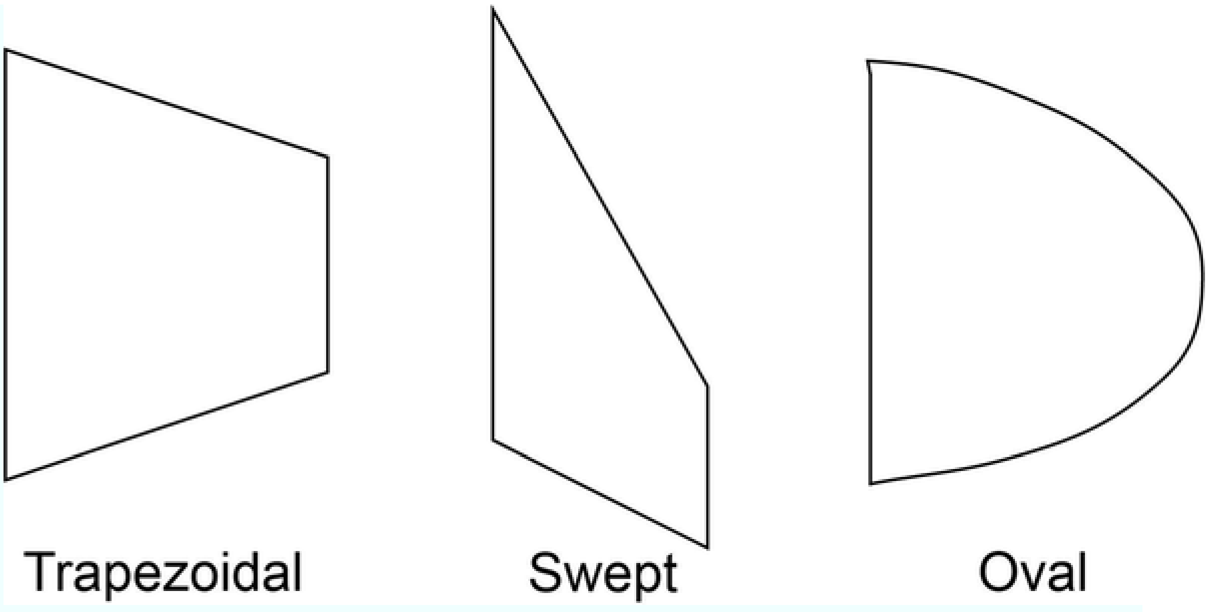


Figure 2-11. Common fin shapes.

As for the number of fins, you should almost always use three fins rather than four. While certain situations might call for using four fins, three fins is best for most rockets because they have less drag than four fins.

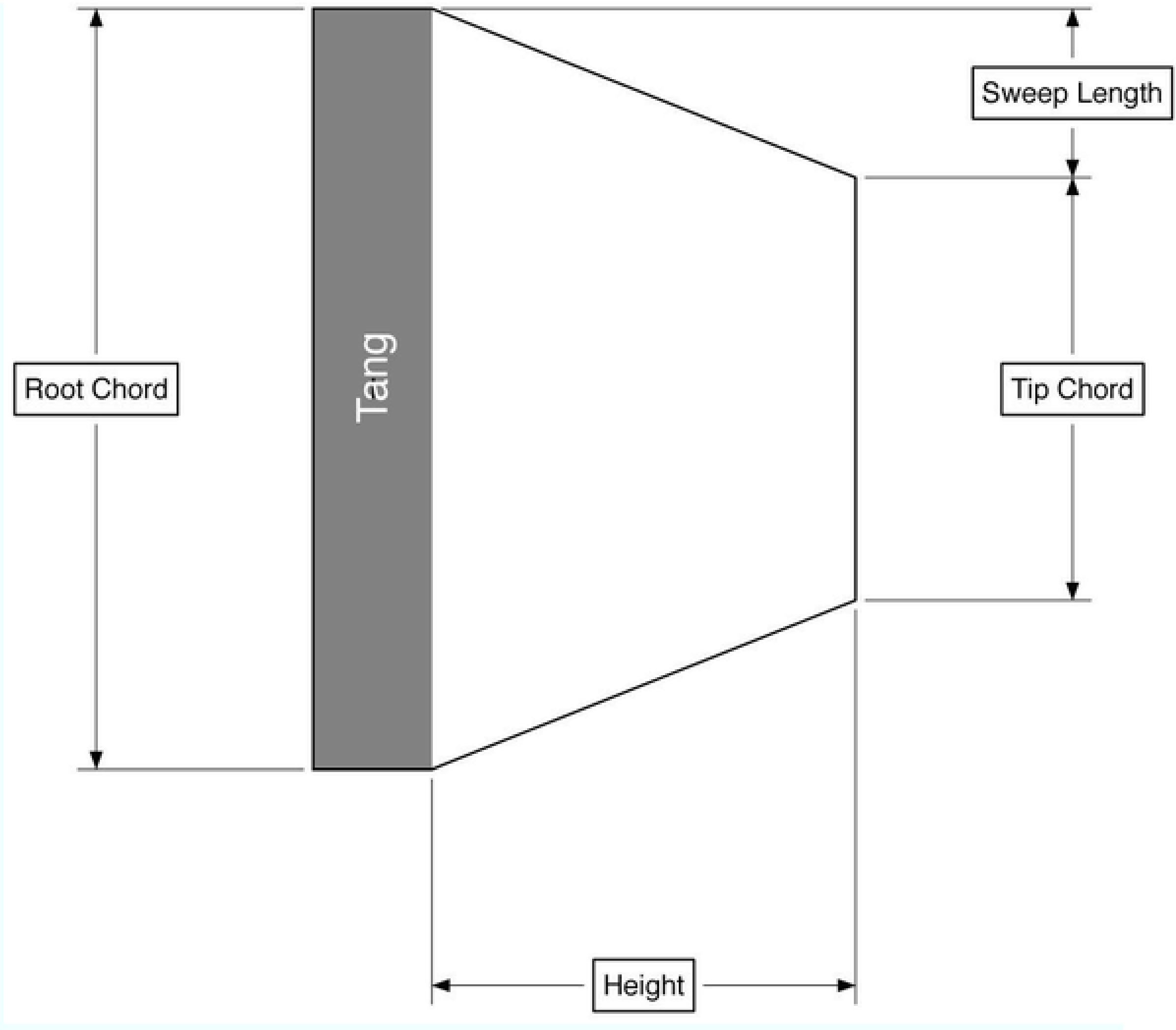


Figure 2-12. Here are the various terms used to describe the shape of a trapezoidal fin.

Working our way down the left side of the dialog in Figure 2-10, the number of fins, fin rotation, and fin cant are all fine. The number of fins is almost always three or four. Three fins is plenty for a stable rocket, and since fins typically account for 40% of the drag, it’s good to stick with three fins unless you have a good reason for using four. *Fin rotation* rotates the fins about the axis of the rocket. Type in 45°, for example, and see how the fin position changes. This feature isn’t needed very often. It can be handy on rockets that have two different kinds of fins—you can create two fin sets and rotate one relative to the other. *Fin cant* rotates the fin itself, so the rocket will spin. This is almost never used, since we normally want our rockets to fly straight.

The *root chord* is the length of the fin that is right up against the body tube. For Callisto, use 4 11/16”.

The *tip chord* is the length of the tip of the fin. This is 2 1/2” for Callisto.

The *height* is the distance from the body tube to the tip of the fin. RockSim calls this the *semi-span*, which is more in keeping with aeronautical engineering. Use 3” for Callisto.

Entering Values

Most engineering programs include a cool feature that makes it easy to enter values as fractions. When we work in inches, it’s very common to talk about values like 4 11/16”, which is how you will usually see the values in this book. Computer programs almost always use decimal notation, so you will see 4.688 as the value in the dialog.

The unsuspected and very cool feature you find in many engineering programs, though, is that you can type in “4 11/16” and the program will do the math for you.

The *sweep length* is the distance from the leading edge of the fin at the fin root to the leading edge of the fin at the fin tip, measured in the direction of air flow. Use 1 3/4” for Callisto. This parameter is fun to play around with: you can get a dramatic swept fin with a larger value, or you can make the value negative, giving a reverse sweep.

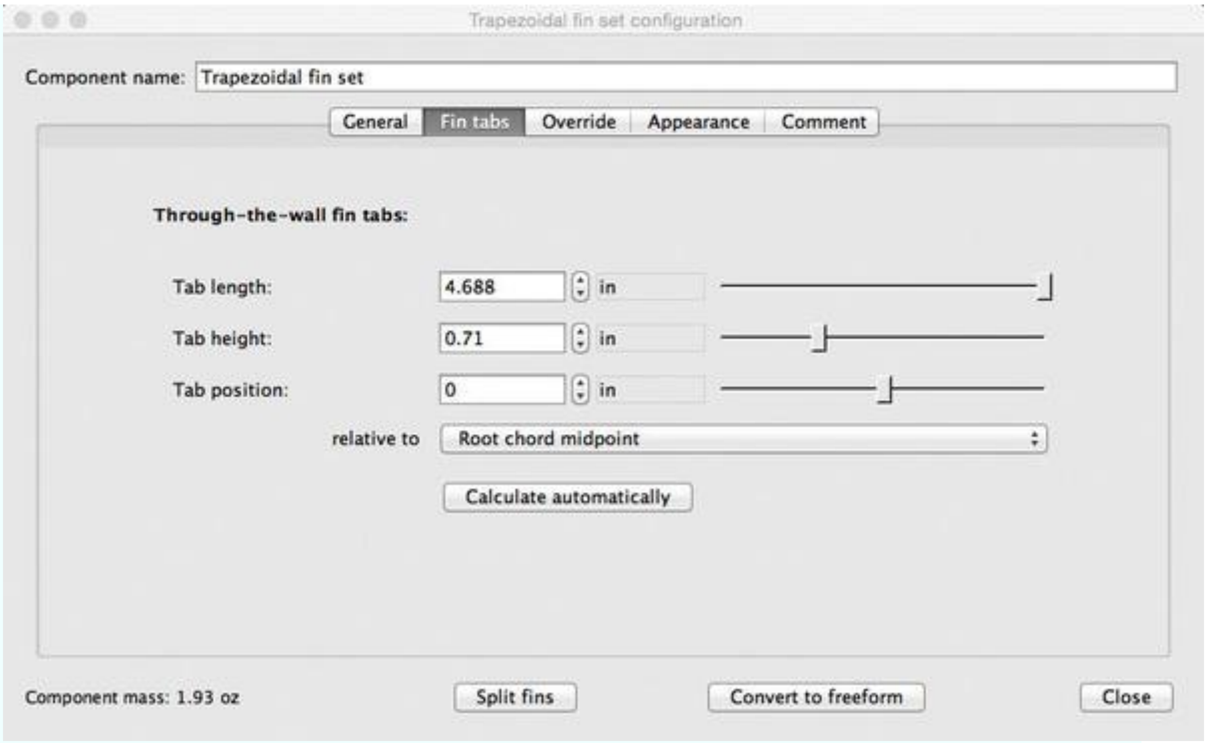
The *sweep angle* exists so you can type in an angle rather than calculating the sweep length. They control the same aspect of the fin design. The angle will update if you change the sweep length, and the sweep length will update if you change the angle.

Moving to the right side of the dialog, we see some other parameters. The *fin cross section* is the shape of the fin presented to the air as it flows over the fin. This has a huge impact on the overall drag on the rocket. We’re going to round the fins on Callisto, so choose “Rounded” from this drop-down menu.

Callisto’s fins will be cut from 1/8”-thick aircraft plywood. Enter 1/8 for the thickness and select “Plywood (birch) (0.63 g/cm^3)” for the component material.

Finally, enter –1/2 for the “plus” value, which will move the fins forward 1/2” from the bottom of the body tube.

Click on “Fin tabs.” Most high-power rockets use a sturdy fin mounting technique called *through-the-wall fins*. The fin isn’t glued to the outer body tube, which is called *surface mount fins*. Instead, it passes through the outer body tube and is glued to the motor tube. The part of the fin that is inside the main body tube is called the *fin tab* or the *tang*. The tab length is usually the same as the fin’s root chord. The tab height needs to be long enough to pass through the outer body tube and reach down to the outer surface of the motor mount. The tab position lets you move the tab forward or backward relative to the fin root. Click the “Calculate automatically” button, and OpenRocket will fill in appropriate default values for the fin tang. The fin dialog should now look like Figure 2-13.



Component name: Trapezoidal fin set

Through-the-wall fin tabs:

Tab length: 4.688 in

Tab height: 0.71 in

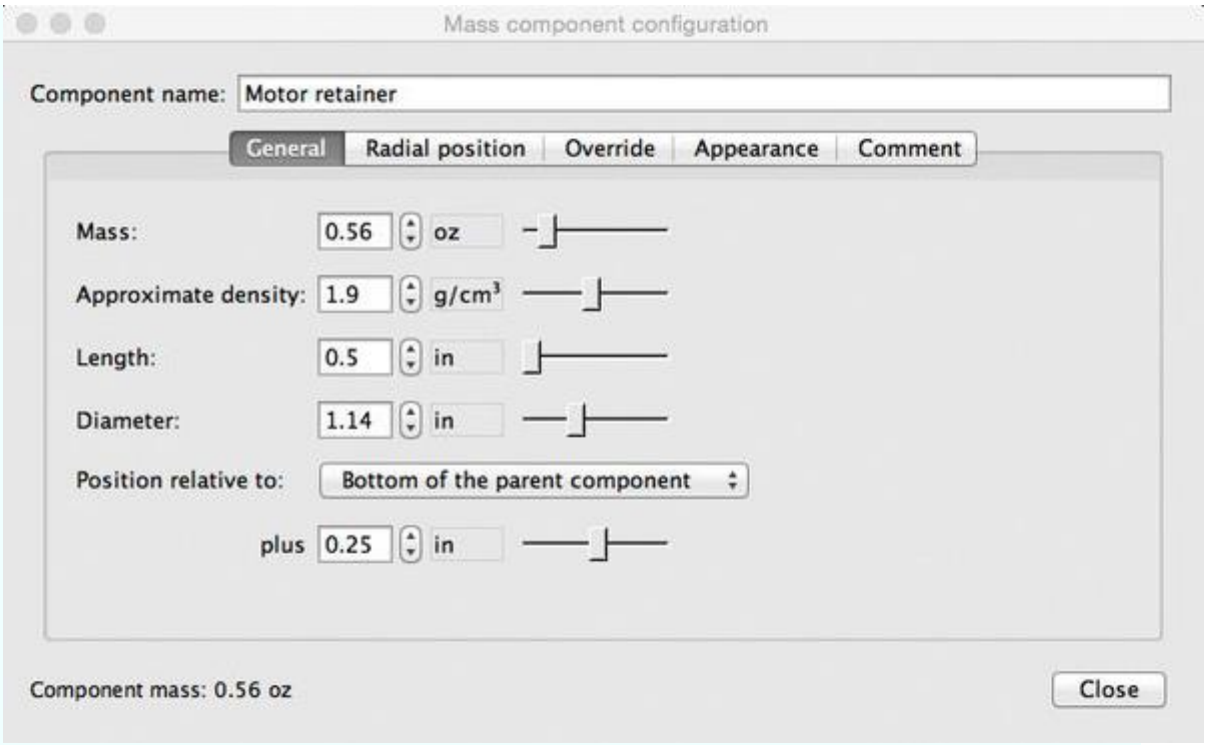
Tab position: 0 in

relative to Root chord midpoint

Component mass: 1.93 oz

Figure 2-13. Add a fin tab using the “Calculate automatically” button.

The last part we need at the base of the rocket is a motor retainer. This is the first of several parts that don’t have much visual effect on the rocket, and that take no part in the drag calculations OpenRocket will do in order to simulate the rocket’s flight. It does have a small impact on the center of gravity, though. We handle these items using a mass component. Select the motor tube, and then click on “Mass component.” You may need to scroll down a bit to find this icon; it’s on the bottom row of icons in the “Add new component” panel. Fill in the dialog as shown in Figure 2-14 to create a mass object at the base of the rocket with a weight of 0.56 oz.



Component name: Motor retainer

Mass: 0.56 oz

Approximate density: 1.9 g/cm³

Length: 0.5 in

Diameter: 1.14 in

Position relative to: Bottom of the parent component

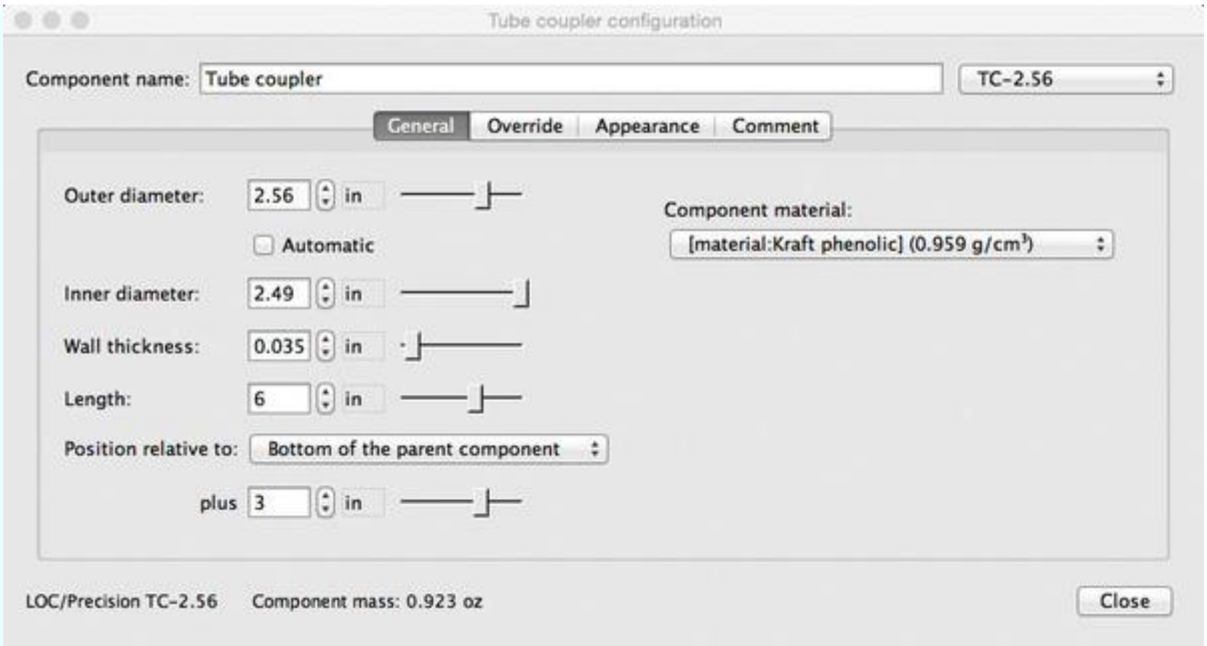
plus 0.25 in

Component mass: 0.56 oz

Figure 2-14. Create a 0.56 oz mass object 1/4” below the end of the motor mount to account for the motor retainer.

With the bottom part of the rocket complete, it’s time to move back to the payload section. The first thing we need to add is a tube coupler. This is a tube that slides snugly into the body tube of the rocket. We’ll use it as the base of the payload section to form a shoulder much like the one on the nose cone. This will slide into the main body tube.

Select the payload tube and add a tube coupler by clicking on the Coupler button. Select LOC TC-2.56 from the parts database. The default length of 6” is perfect. Place the tube coupler 3” from the base of the component, so half of it is in the payload tube and half in the main body tube. Your dialog should look like Figure 2-15.



Component name: Tube coupler

TC-2.56

Outer diameter: 2.56 in

☐ Automatic

Inner diameter: 2.49 in

Wall thickness: 0.035 in

Length: 6 in

Position relative to: Bottom of the parent component

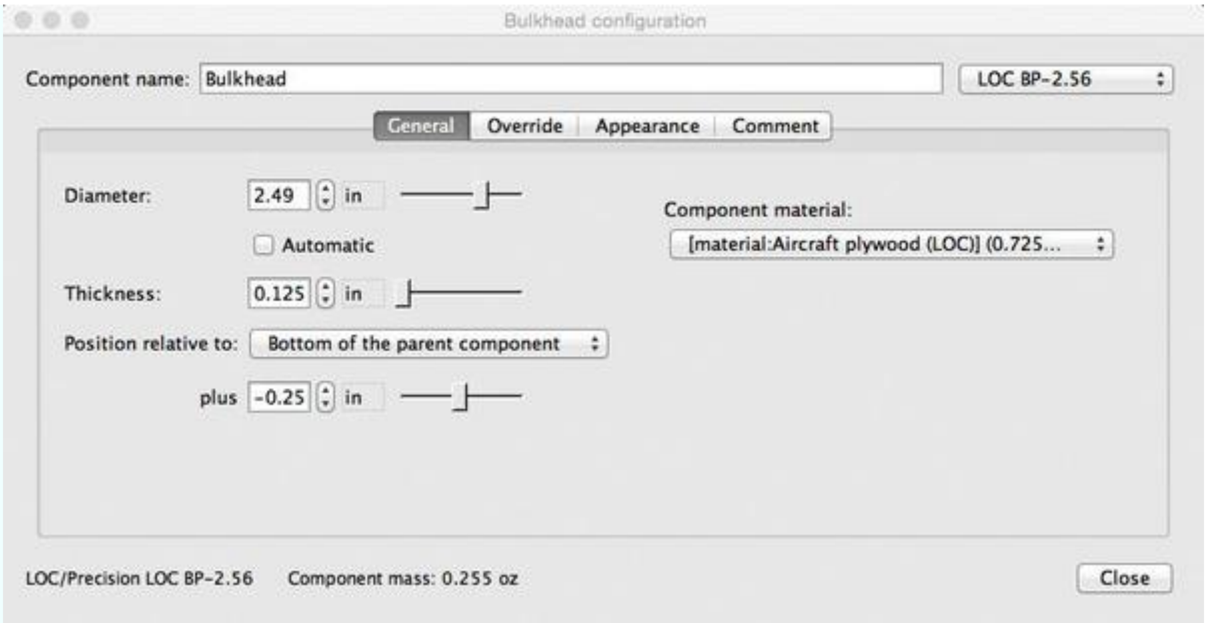
plus 3 in

Component material: [material:Kraft phenolic] (0.959 g/cm^3)

LOC/Precision TC-2.56 Component mass: 0.923 oz

Figure 2-15. Add a 6”-long tube coupler to join the two body tubes.

We’ll close off the bottom of the tube coupler with a plywood *bulkhead*, also called a *bulk plate*. From the database, choose LOC BP-2.56, which is a 1/8”-thick aircraft plywood disk. Position it 1/4” from the bottom of the tube coupler, as shown in Figure 2-16.



Component name: Bulkhead

LOC BP-2.56

Diameter: 2.49 in

☐ Automatic

Thickness: 0.125 in

Position relative to: Bottom of the parent component

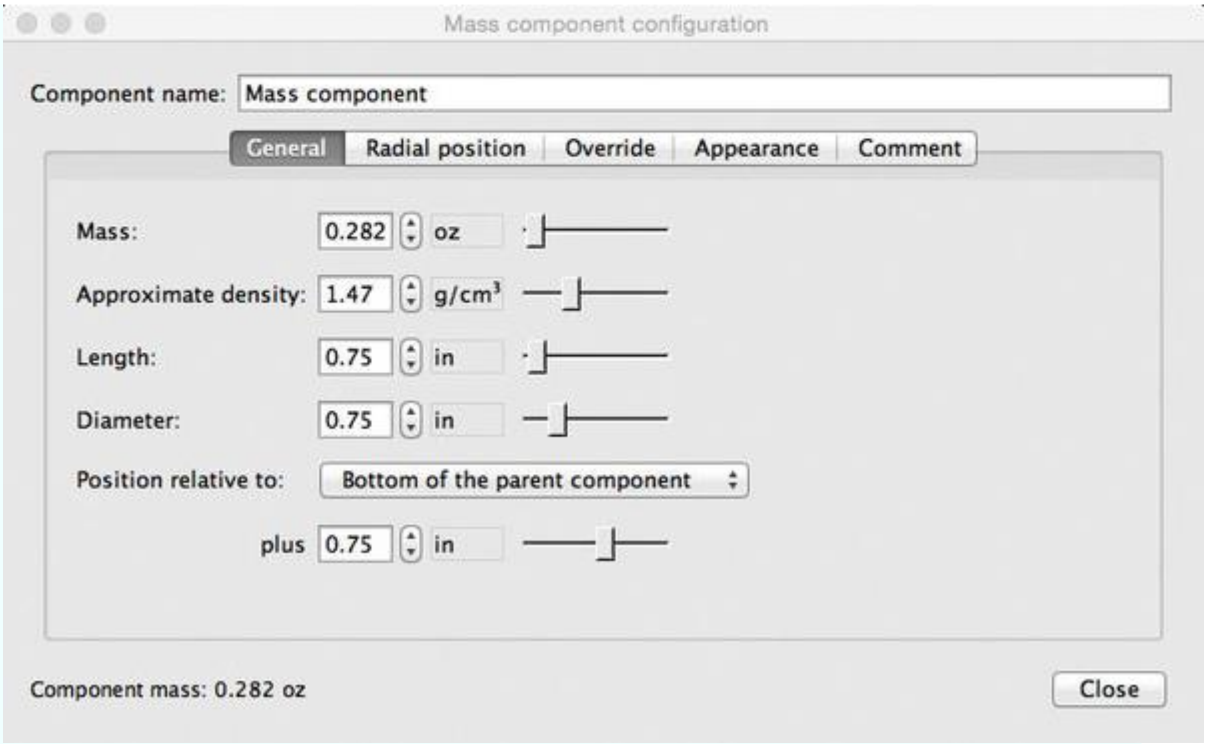
plus -0.25 in

Component material: [material:Aircraft plywood (LOC)] (0.725...

LOC/Precision LOC BP-2.56 Component mass: 0.255 oz

Figure 2-16. Add a 1/8”-thick bulkhead 1/4” from the base of the tube coupler.

Finally, add a 0.282 oz mass object just below the bulkhead, as shown in Figure 2-17. This represents the eye bolt that we will use as an attachment point for the shock cord.



Component name: Mass component

Mass: 0.282 oz

Approximate density: 1.47 g/cm³

Length: 0.75 in

Diameter: 0.75 in

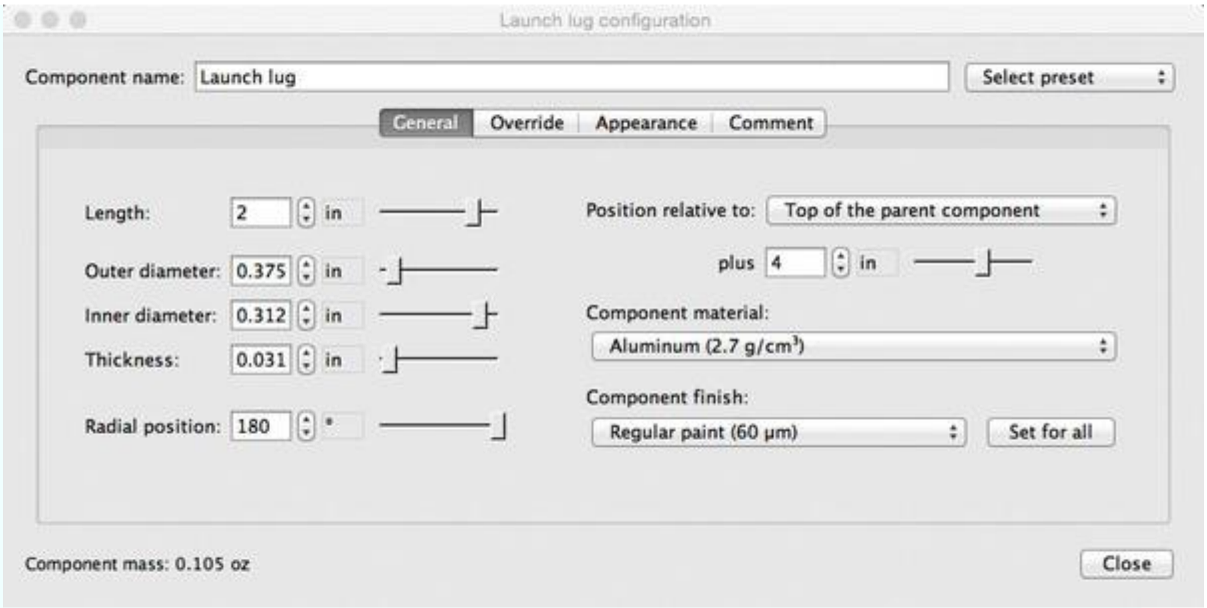
Position relative to: Bottom of the parent component

plus 0.75 in

Component mass: 0.282 oz

Figure 2-17. Add a mass object at the base of the tube coupler to represent an eye bolt.

Our rocket will lift off using either launch lugs or rail buttons. Let’s start with the launch lugs, which will be cut from 5/16” aluminum or brass tubes; each will be 2” long. Both brass and aluminum are commonly used, and both work fine. For me, it generally comes down to what I find at the hobby store the day I go to buy parts. Add one launch lug 2” from the base of the rocket and another 4” from the top of the main body tube. The latter of these is shown in Figure 2-18.



Component name: Launch lug

Length: 2 in

Outer diameter: 0.375 in

Inner diameter: 0.312 in

Thickness: 0.031 in

Radial position: 180 °

Position relative to: Top of the parent component

plus 4 in

Component material: Aluminum (2.7 g/cm^3)

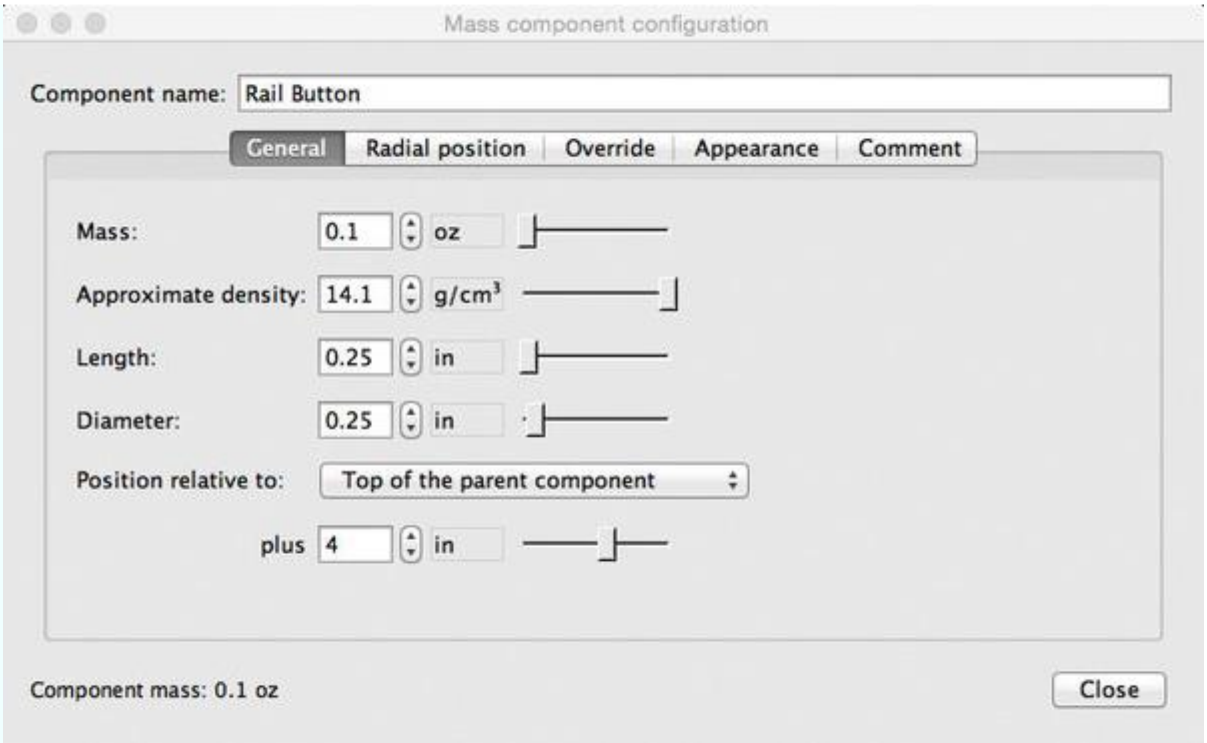
Component finish: Regular paint (60 μm)

Component mass: 0.105 oz

Figure 2-18. Add two launch lugs made from aluminum or brass, one 2" from the base of the rocket and the other 4" from the top of the main body tube.

Callisto can be flown on either mid- or high-power motors. Mid-power rockets are usually flown from launch rods, while high-power rockets are usually flown from launch rails. The construction details show both, which is the way I built Callisto. As it turns out, that was a good choice. I've flown Callisto from both launch rails and launch rods. You can do the same, or choose one of the two for your rocket.

Oddly, neither OpenRocket nor RockSim has a predefined way to add a rail button. The reason this is strange is that rail buttons add to the overall drag on the rocket. They really aren't that heavy, though, so you have a choice. You can add them as a launch lug, which is not perfect but does add a bit of drag, or you can add them as a mass object. Figure 2-19 shows a rail button defined as a mass object weighing 0.1 oz. Add two of these, 1" from the base of the rocket and 4" from the top of the main body tube. For added realism, extend them from the default location at the center of the rocket to 1.28", right on the edge of the body tube, and use the "Radial position" tab to rotate the rail buttons so they are not in line with the fins.



Component name: Rail Button

Mass: 0.1 oz

Approximate density: 14.1 g/cm³

Length: 0.25 in

Diameter: 0.25 in

Position relative to: Top of the parent component

plus 4 in

Component mass: 0.1 oz

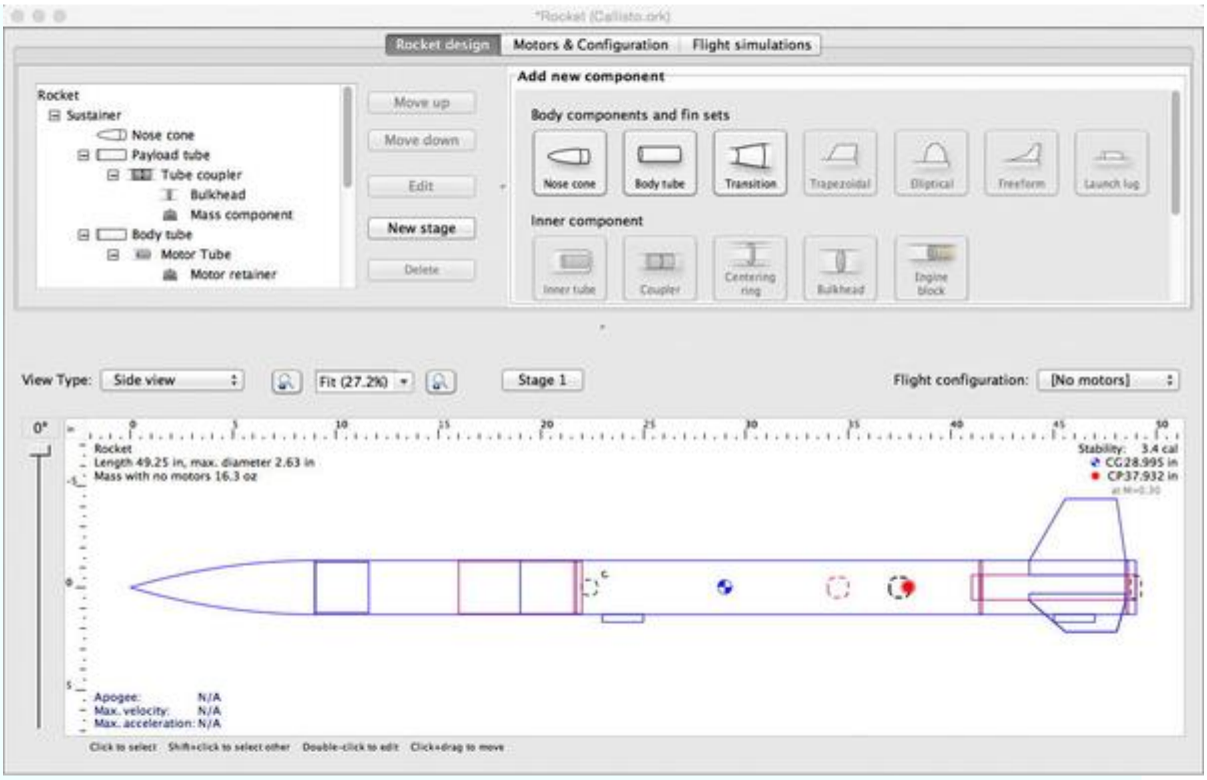
Figure 2-19. Add two rail buttons. Each has a mass of 0.1 oz. One is 1” from the base of the rocket, while the other is 4” from the front of the rocket.

We still need to add a recovery system. By now the drill should be pretty familiar. Select the main body tube and click on the Parachute button. Add an LP-36 parachute to the rocket. The parachute will tend to be pushed toward the base of the body tube, right up against the shock cord and motor mount, so give it a position 15” from the top of the main body tube.

Select the main body tube again and add a shock cord. The shock cord should be 60” long, made from 1/8” braided nylon. Place it 18” from the top of the main body tube.

Finally, we will use two quick links to attach the parachute to the shock cord and the shock cord to the payload bay. We’ll cover quick links in more detail later. For now, add them as two mass components, each 0.3 oz. Place them 18” from the front of the main body tube, right in the middle of the shock cord.

That completes the design of the rocket (Figure 2-20). What you have at this point is a good plan for the rocket, as well as a complete parts list. You may want to explore the various options in OpenRocket before moving on. For example, if you print the rocket, RockSim will give you full-size fin patterns, centering ring patterns, fin placement guides, and a printed parts list.



View Type: Side view
Fit (27.2%)
Flight configuration: [No motors]

Rocket
Length 49.25 in, max. diameter 2.63 in
Mass with no motors 16.3 oz

Stability: 3.4 cal
CG:28.995 in
CP:37.932 in

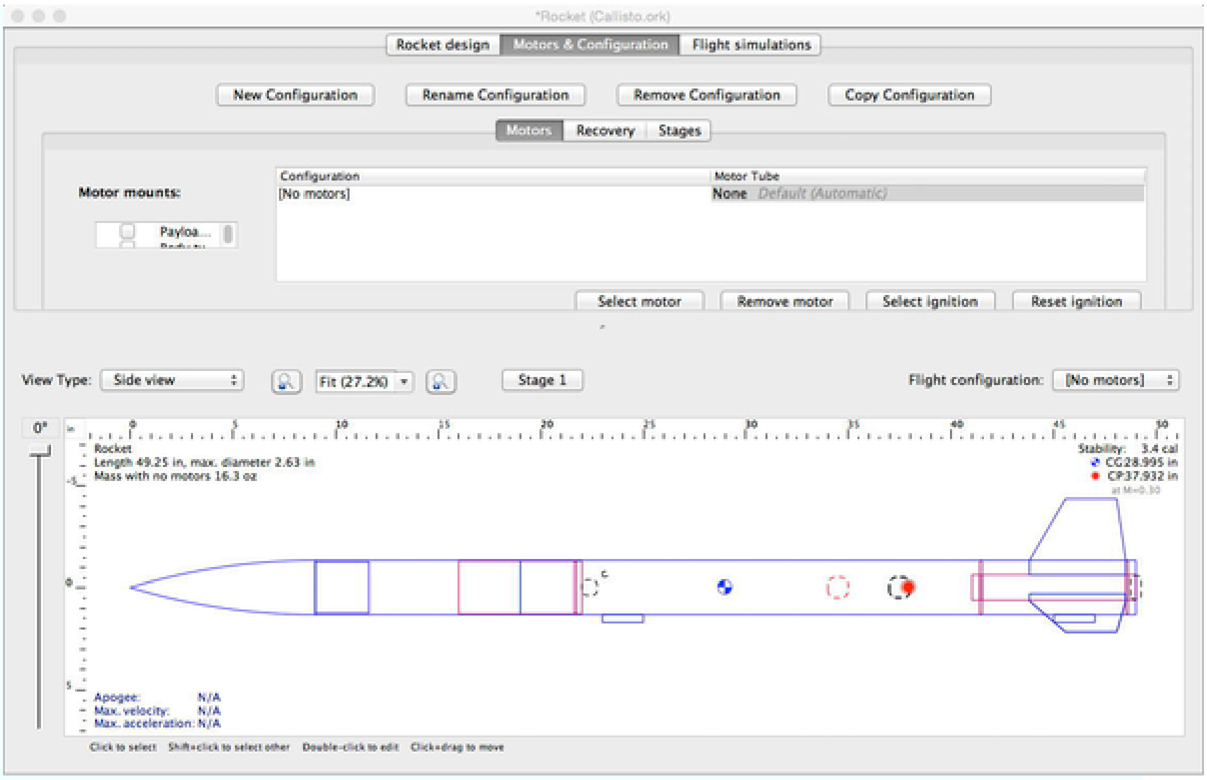
Apogee: N/A
Max. velocity: N/A
Max. acceleration: N/A

Figure 2-20. The completed rocket design gives us a visual plan plus a parts list.

Simulating Flight

The next step is to make sure the rocket will fly with the motors we intend to use.

Click on the Motors & Configuration tab, and then click on the New Configuration button (Figure 2-21). This adds a new flight configuration, with settings for the motor that we will use, the recovery system, and (if we were using them) how staging would work in a multistage rocket. The initial configuration has everything we need preset for Callisto except the choice of motor.



Motor mounts:

Configuration	Motor Tube
[No motors]	None *Default (Automatic)*

View Type: Side view

Fit (27.2%)

Flight configuration: [No motors]

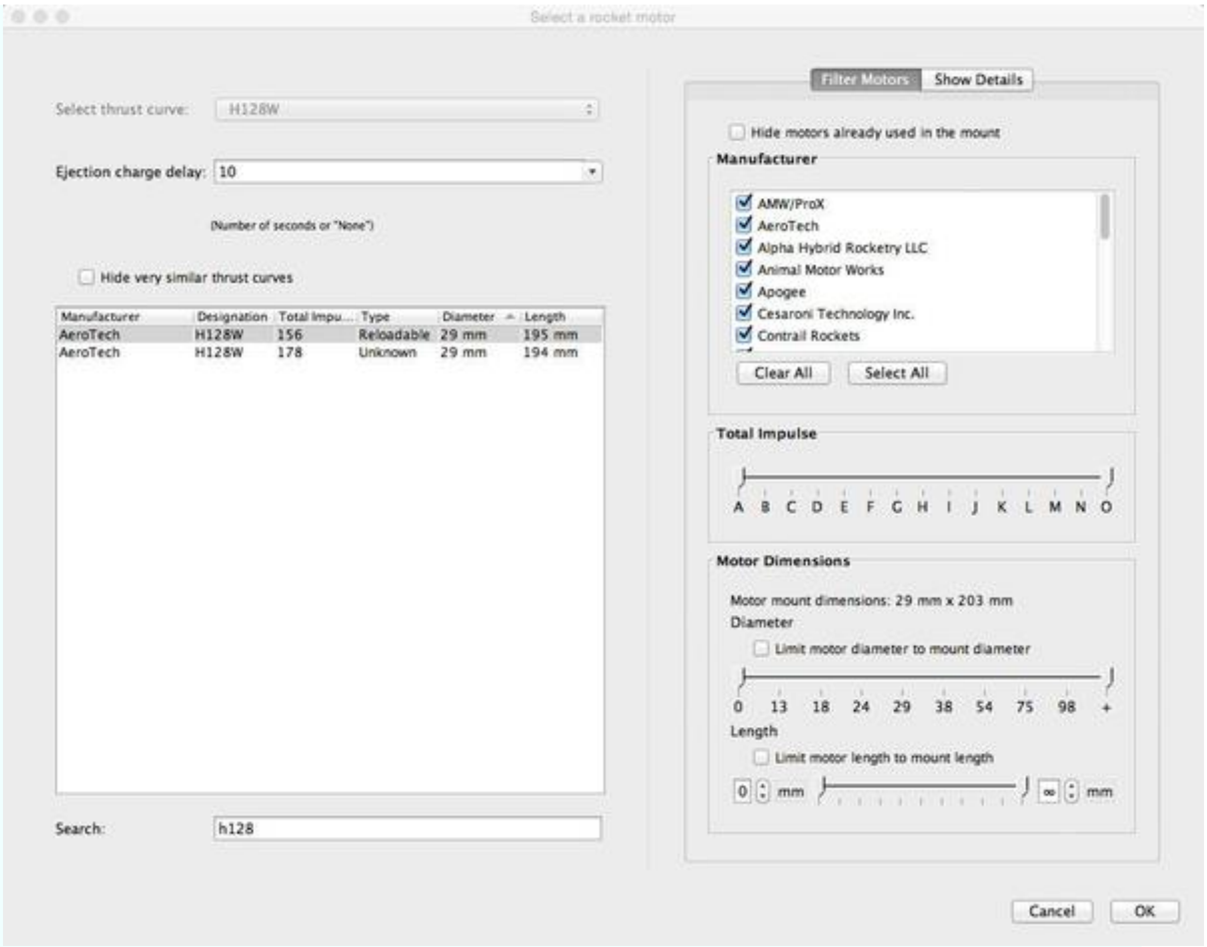
Rocket
Length 49.25 in, max. diameter 2.63 in
Mass with no motors 16.3 oz

Stability: 3.4 cal
CG:28.995 in
CP:37.932 in

Apogee: N/A
Max. velocity: N/A
Max. acceleration: N/A

Figure 2-21. Create a new flight configuration by clicking on the Motors & Configuration tab, and then on the New Configuration button.

Double-click on None under Motor Tube. This brings up the dialog in Figure 2-22. There are a lot of motors listed! You could scroll through the list, but let's make it a bit easier. One of the motors we will simulate is the AeroTech H128W-M. Type "h128" in the search line and all but two motors vanish.



Select thrust curve: H128W

Ejection charge delay: 10

(Number of seconds or "None")

☐ Hide very similar thrust curves

Manufacturer	Designation	Total Impu...	Type	Diameter	Length
AeroTech	H128W	156	Reloadable	29 mm	195 mm
AeroTech	H128W	178	Unknown	29 mm	194 mm

Search: h128

☐ Hide motors already used in the mount

☑ AMW/ProX
☑ AeroTech
☑ Alpha Hybrid Rocketry LLC
☑ Animal Motor Works
☑ Apogee
☑ Cesaroni Technology Inc.
☑ Contrail Rockets

Motor mount dimensions: 29 mm x 203 mm

☐ Limit motor diameter to mount diameter

☐ Limit motor length to mount length

0 mm – ∞ mm

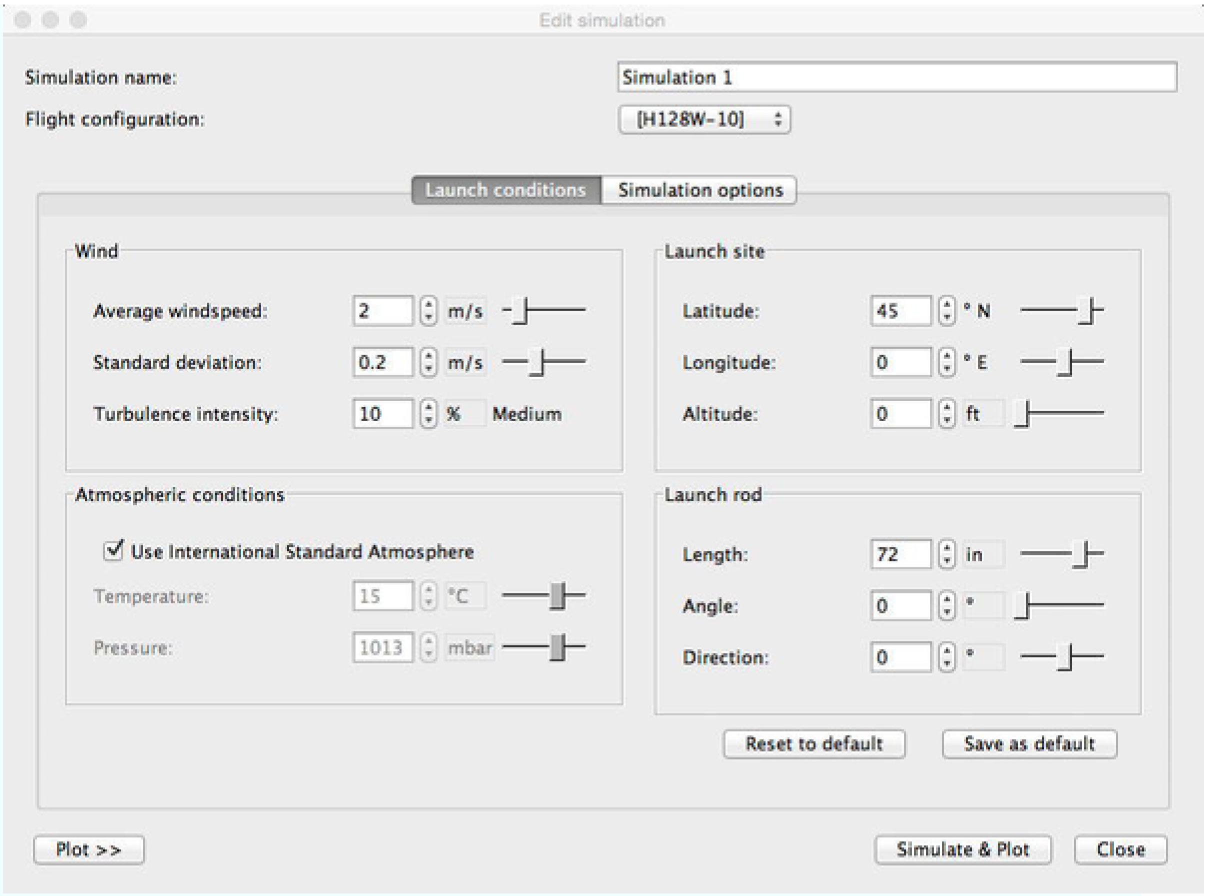
Figure 2-22. Double-click on None under Motor Tube to select a motor. Use the search line to quickly narrow the search for motors.

There are two motors to choose from, and both are listed as AeroTech H128W motors. This presents an interesting quandary, especially since the motors differ. Which is right? Oddly, both.

Even though two rocket motors may have the same designation, individual motors vary a bit from one motor to the next. The typical standard tolerance is 10% from the labeled amounts. The notes for the second motor indicate the data is from a test conducted by TRA, one of the organizations for rocketry in the United States. The first set of data does not have any notes in the motor data itself, but appears to match the thrust curve on the AeroTech data sheets. You can choose either one and get a good representation of the motor's performance. I selected the first because it has the different delay times properly entered from the AeroTech data sheets for the short, medium, and long delays, while the second motor profile only has the medium delay time listed. It's even fair to create two separate simulations, one with each set of data, and compare them.

Explore this pane a bit, looking at the various dialogs that can be used to set aspects of the flight. We'll use many of these in later parts of the book, but the default settings will work well for Callisto.

The next step is to simulate a flight with this motor and see if it will work for Callisto. Click on the "Flight simulation" tab. Select the first simulation, then click "Edit simulation." This brings up the dialog shown in Figure 2-23.


Edit simulation

Simulation name: Simulation 1

Flight configuration: [H128W-10]

Wind

Average windspeed: 2 m/s

Standard deviation: 0.2 m/s

Turbulence intensity: 10 % Medium

Launch site

Latitude: 45 ° N

Longitude: 0 ° E

Altitude: 0 ft

Atmospheric conditions

☑ Use International Standard Atmosphere

Temperature: 15 °C

Pressure: 1013 mbar

Launch rod

Length: 72 in

Angle: 0 °

Direction: 0 °

Figure 2-23. Set the simulation parameters in the "Edit simulation" dialog.

This dialog lets you change the various things that might change from flight to flight. The values on the left relate to the current weather. You should not fly any rocket in winds over 20 mph; within that limit, you can set the current wind speed, as well as the standard deviation, which changes how variable the wind is. The turbulence intensity is just another way of setting the standard deviation. It is the percentage of the standard deviation with respect to the wind speed. The two terms are linked; changing one will update the other.

As the weather changes, the temperature and pressure change. The values in the “Atmospheric conditions” section let you adjust the barometric pressure and temperature to match the weather on flight day. These can cause a noticeable change in the simulated altitude of the rocket.

The default values for wind and weather are fine for testing the rocket design. If you want to coax all of the accuracy you can out of the simulator, adjust these values on launch day to match the actual weather.

Pressure and Altitude

There are two settings that seem related, but that the simulator treats separately. The atmospheric pressure obviously goes down as the altitude increases, but the two are not linked by the simulator. Why?

It turns out that the barometric pressure reported by weathermen is adjusted for sea level. That makes it easier to see if the pressure is higher or lower than normal, which is an important consideration for predicting weather. The barometric pressure in OpenRocket is also adjusted for sea level. If you enter a value, enter the value reported by the closest weather station or airport.

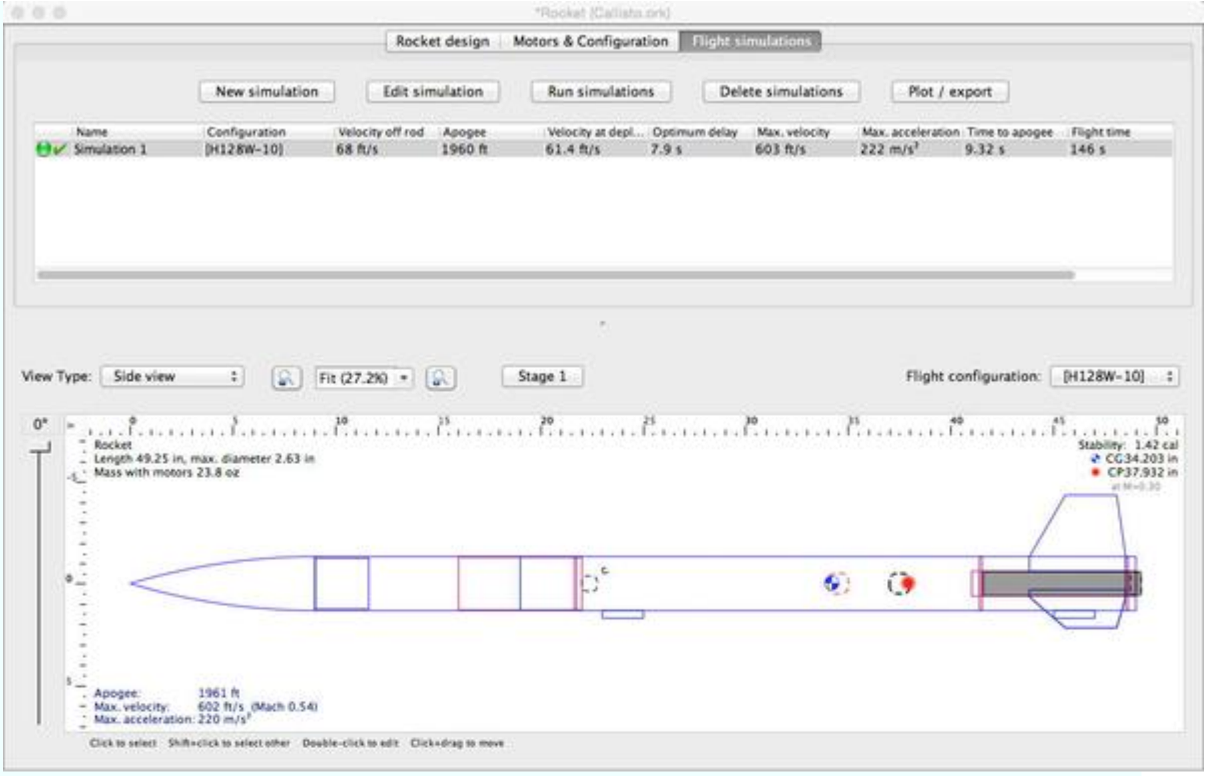
The altitude is used to adjust for lower pressure as the launch height changes. It doesn’t show up in the pressure field, but you can see from running a few simulations that it is definitely used for calculating the rocket’s performance.

The longitude and latitude for the flight are not really important for low-altitude flights like the one we are simulating with Callisto. You can certainly set them, but they won’t really change the results much. The altitude can be very important, though. This is the altitude of the launch pad on launch day. Here in Albuquerque, our flying field is at about 5,000 feet above sea level. We lose about 20% of the atmosphere by living nearly a mile high, and that can have a big impact on the performance of a rocket. While you don’t need to get the altitude absolutely correct, you should set it to within about 500 feet of the correct value.

Finally, set the launch rod length, angle, and direction relative to the wind. A 6-foot-long launch rail is pretty common, and a 4-foot-long

1/4” launch rod is also common. If you are using your own launcher, enter the correct value for the length. If you will be using a club launcher, check with someone in the club to see how long the launch rod or launch rail will be. The angle should generally be 0°. The direction, which is the angle of the launch rod relative to the wind, doesn’t matter unless you adjust the vertical angle of the launch rod.

Once the appropriate values are set, close the dialog and press the “Run simulation” button. It will only take a moment before the various values are filled in. If all of the values for the flight appear reasonable to the simulator, there will be a green circle and a green check mark at the left of the simulation. If the check mark is red, click on it to find out what the simulator thinks is wrong with the flight. The flight should show values fairly close to those in Figure 2-24. There may be slight differences due to specific settings you selected. There will even be small differences if you run the simulation several times; these are from random numbers selected based on your simulation settings.



	Name	Configuration	Velocity off rod	Apogee	Velocity at depl...	Optimum delay	Max. velocity	Max. acceleration	Time to apogee	Flight time
● ✓	Simulation 1	[H128W-10]	68 ft/s	1960 ft	61.4 ft/s	7.9 s	603 ft/s	222 m/s²	9.32 s	146 s

View Type: Side view
Fit (27.2%)
Stage 1
Flight configuration: [H128W-10]

Rocket
Length 49.25 in, max. diameter 2.63 in
Mass with motors 23.8 oz

Stability: 1.42 cal
CG:34.203 in
CP:37.932 in

Apogee: 1961 ft
Max. velocity: 602 ft/s (Mach 0.54)
Max. acceleration: 220 m/s²

Figure 2-24. Select the simulation and run it by pressing the “Run simulation” button.

There are several important values that you need to check before flying the rocket. The first is the “Velocity off rod.” This is the speed of the rocket as it leaves the end of the launch rod or launch rail. The rocket can veer off course if it is not traveling fast enough for the fins to guide the rocket through the air. Make sure the value is at least 30 mph, which is about 44 feet per second.

The apogee is the prediction for the maximum height of the rocket above ground level. Make sure this is at least 10% lower than the limits imposed by the FAA for the day and launch site where you expect to fly. You don’t want to bust an FAA ceiling; this could make it difficult or impossible for the club you are flying with to get FAA waivers in the future, making you a very unpopular person.

The velocity at deployment is the speed the rocket will be traveling when the parachute deploys. If the rocket is traveling too fast, the parachute could tear or it could pull the shock cord through the side of the body tube. You might think that would be pretty unlikely, but it happens often enough to have a name! Ripping through the side of a body tube with the shock cord is called a *zipper*. Different rockets and parachutes can withstand different speeds, of course. OpenRocket will flag any speed over about 65 ft/s as being a problem. You should be able to do much better than this by selecting an appropriate motor and ejection charge delay. The next column, “Optimal delay,” tells you the best possible value for the ejection charge delay. Use the ejection charge closest to this value, going a bit over rather than a bit under if two values are about the same difference from ideal. For example, if the ideal time is 12.2 seconds, and you are choosing between the 10-second medium delay for an H128W and the 14-second long delay, go for the long delay. That lets the rocket hit apogee and turn over before the parachute comes out, slowing the ascent.

The time to apogee and flight time tell you about how long the flight will last.

Finally, check the stability number that appears at the top right of the pane with the rocket drawing. This is the location of the center of pressure, minus the center of gravity, divided by the diameter of the body tube. The stability number should be at least 1. A stability number lower than 1 is not a guarantee that the rocket is unstable, but 1 is the generally accepted number that indicates a very high likelihood of stability. Bigger numbers are better, but only up to a point, so avoid very large stability numbers too. Overly stable rockets tend to turn quickly into the wind, which can be a problem if a gust of wind comes along just as the rocket leaves the pad. Avoid stability numbers above 4 or so unless you have a very good reason to exceed this limit—and make sure to carefully research what this will do to your rocket. A larger number doesn’t guarantee problems, but you will need to be careful when flying it on gusty days.

You need to make changes to your design if the stability factor is less than 1. You can move the center of pressure farther back on the rocket by making the fins larger, sweeping them, or removing boat tails. You can move the center of gravity forward by adding weight to the nose. It’s worth taking a moment to experiment with the simulator. Try making the fins smaller and larger, adding small fins at the front of the rocket, and adding weight to the nose or payload section. Take a look at what these changes do to the stability factor.

You will have some options when flying the rocket, so add a few more simulations to account for different motor choices. For example, go ahead and try an AeroTech F52-8. This is a mid-power motor that doesn’t need an FAA clearance. You might want to fly your rocket on this motor before attempting your Level 1 certification. You should try a Cesaroni H163-WT-9 motor, too.

Finding Motor Data

You may find motors that are not listed in the default database. If so, do an online search. All rocket motors are tested, and the results are available in formats that are used by the popular simulators. If there is a new motor, the data will definitely be available in a format you can download and use.

Chapter 3. The Level 1 Rocket Continued

Parts and Tools

With the design of the rocket in hand, it’s easy to generate a parts list. Table 3-1 shows the parts you will need, including part numbers from the LOC Precision website. LOC Precision is one of several good companies that sell parts for high-power rockets. We’ll try parts from a few different companies as we build the rockets throughout this book.

You can make a lot of substitutions for the parts listed, and you will need some basic tools and supplies to build your rocket, too (see Table 3-1). Be sure to read the chapter all the way through before you decide what to order.

Part	Description
Nose cone	The nose cone for the rocket.
Payload bay	The rocket design has several components that make up the payload bay: a 10” length of body tube, a tube coupler, a plywood bulkhead that closes off the bottom of the tube coupler, and an eye bolt used to attach the parachute. You can buy these separately, but LOC Precision sells them in a package. It’s easier and cheaper to get the package.
2.56” airframe	This is the main body tube. It is 30” long.
Motor mount tube	Motor mount tubes from LOC are a bit thicker than body tubes. They come in 34” lengths, which we will cut down to 8”. There will be plenty of tube left over for the next rocket! I you decide to get a motor mount from another source, be sure it is designed for 29 mm motors and is at least 8” long.

Part	Description
Motor retainer	There are a lot of choices for motor retainers (see “The motor retainer”). LOC sells a fine one made by Aero Pack.
Centering ring for 29 mm motor mounts to 2.56” body tubes (2)	The plywood centering rings hold the motor mount in the mai body tube. You need two. LOC Precision sells them in pairs.
1/8” aircraft plywood fin stock	You can get this from most hobby stores, or order it from LOC Precision when you buy the other parts.
Launch lugs	LOC Precision sells a paper launch lug for 1/4” launch rods. I will work just fine. I like using a 5/16” inside diameter brass o aluminum tube. Take your pick; just make sure you get at leas 4” of tube.
Rail buttons	This is the rail button used when launching from a rail instead of a launch rod. The rocket is shown built with both launch lugs and rail buttons. You may not need both. See “Launch lugs and rail buttons” for details.
Parachute, 36”	You will need a 36” nylon parachute for recovery.
Nylon shock cord	There are several options here (see “Shock cord” for details). LOC sells a 12-foot piece of tubular nylon that works quite well.
Recovery blanket	This is a flame-proof sheet of fabric that protects the parachut and most of the shock cord from the ejection charge. While a 6” square is adequate, I prefer a larger one, at least 9”. See “Recovery blanket” for some thoughts on this.
Shock cord sleeve	This is optional, but a really good idea. This is a flame-proof sleeve that fits over the lower part of the shock cord. See “Shock cord sleeve” for details.
Quick links (2)	These are used to connect the shock cord to the parachute and

Part	Description
	payload bay. Get two. They are available from hardware store or directly from LOC Precision. There are several sizes, generally given by the thickness of the wire used to form the link. Get one that will fit over the eye bolt in the payload bay. The 1/8” quick links I have tried all work with the eye bolt that LOC Precision ships with its payload bay.
1/8” x 3/4” aluminum stock	You will use a short piece of aluminum to make nuts for the rail buttons. You can find suitable strips of metal at most hardware stores. You can also avoid making your own nuts; see “Adding Launch Lugs and Rail Buttons”for details on installing the rail buttons.
#4 1/2”-long pan head screws (3)	Used to attach the nose cone to the payload bay.

Table 3-1. Parts list

Part	Description
Hobby knife	Get a hobby knife with several extra blades.
Cutting board	You will need an 18” x 24” cutting board or shop work surface.
Epoxy glue	Get both fast- and slow-setting glue (generally labeled 5-minute and 3 respectively). Buy the 4 1/2 oz bottles rather than the small self-mixin also use wood glue for this rocket. See “You Can Also Use Wood Glu
Rubbing alcohol	Used to thin or clean up epoxy glue.
Paper towels	Used to clean up messes, especially epoxy glue messes.
Wax paper	Used to mix epoxy glue and to protect your working surface from glu

Part	**Description**
Popsicle sticks	Used to mix and apply epoxy glue. You can find packages of popsicl craft sticks, at hobby and craft stores. Toothpicks are also handy whe applying small amounts of glue.
Disposable gloves	Get a box of 100 disposable latex gloves. Wear these any time you ar epoxy.
Flashlight	You will need a flashlight to peer into the body tube to check glue fil
Dental floss	Use dental floss wrapped around centering rings to pull them out of t dry fitting.
8-32 tap	This is used to create a threaded hole for a size 8-32 screw. The tap w with a drill bit that is the right size for drilling the hole that the tap wi avoid this tool if you like; see “Adding Launch Lugs and Rail Button
90° aluminum	Get a piece of 90° aluminum from the hardware store, about 1” on ea This is used to draw long straight lines on body tubes. Look ahead to are not sure what this stuff looks like.
WD-40	Use WD-40 or some other light oil to cool and lubricate metal parts w drilling. There are a lot of substitutes.
Loctite	Use Loctite or a similar product on screws and nuts to keep the vibrat from jostling the screws loose.
Sandpaper	You will need medium grit and extra fine grit sandpaper.
Sanding block	A small block of wood (about 0.75” x 1.5” x 2”) will do nicely.
Tape	All sorts of tape are useful. Blue or green painter’s tape is used for m painting. Brown masking tape sticks better, and is frequently used fo holding things in place. Duck tape is used when more strength is nee
Paint	Enamel or acrylic paint works well.

Table 3-2. Tools and supplies

Where to Buy Parts

LOC Precision

> You can buy all of the parts for this rocket from LOC Precision, and quite a few of the tools and supplies.

Wildman Rocketry

> Wildman Rocketry makes some of its own parts but also carries parts from other manufacturers, including LOC Precision. Check the prices; one may be less expensive than the other. There is one reason you might end up ordering from Wildman Rocketry, though: Wildman also carries motors. You can order the rocket parts and motors all at once.

There are a number of other great rocketry companies that sell equivalent parts. Some of them will show up in later chapters as we build rockets that explore other construction techniques.
Check Appendix A for a complete list of vendors.

TIP

You may want to get in touch with your local rocket club before ordering a motor or a reload for the motor. Some clubs have loaner motor hardware you can use until you are ready to commit to buying your own, although that’s more common for larger motors than for a Level 1 H motor. The club may also help organize the members as they order motors, so several people can order at once. This saves some on shipping costs, especially for the hazardous materials fee you will be charged when ordering a high-power motor. This fee is currently about $28 per order, whether you order one motor or several.

A Detailed Walk-Through of the Parts List

This is the first rocket in the book, so we’re going to spend a fair amount of time on the parts list, looking at parts for this rocket as well as some alternatives you might consider. This is the place you will end up flipping back to when you want to consider different parts. Figure 3-1 shows the parts you’ll need.

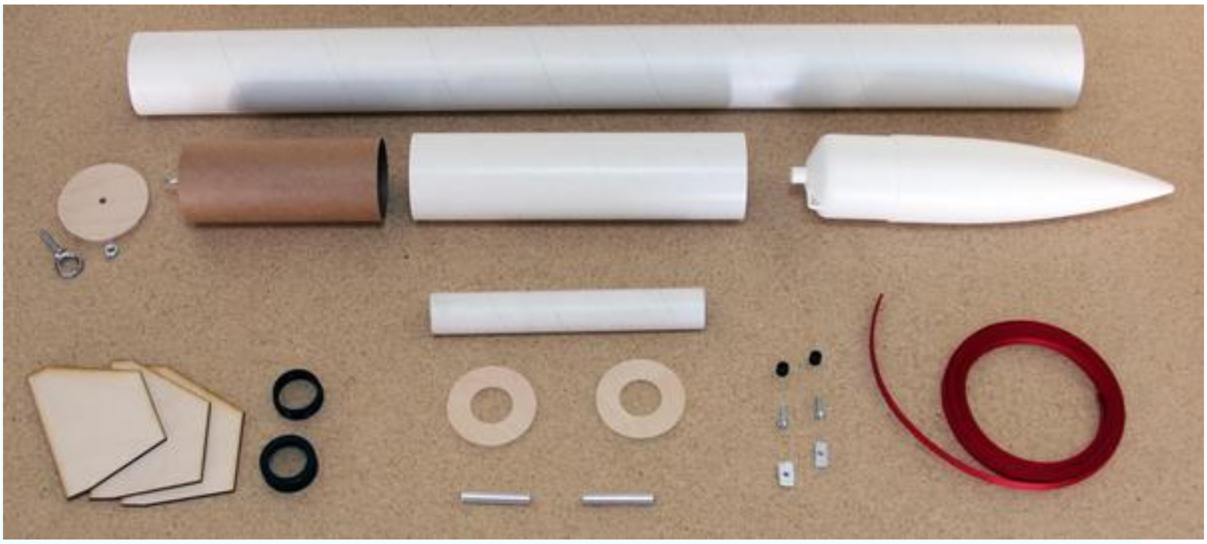


Figure 3-1. Here is a visual version of the parts list for Callisto. See the text for many possible substitutions.

AIRFRAME AND MOTOR MOUNT TUBES

Body tubes form the basic airframe for almost all rockets. Sure, there are a few odd rockets that do things very differently, but the parts you see when you look at most rockets are the body tube, nose cone, and fins. The outer body tube is also called an airframe, while a tube inside the rocket, used to hold a motor, is called a motor tube. They have different names, even though they might be made from the same material.

Body tube in mid- and high-power rockets are made from a variety of materials (see Figure 3-2). Callisto is made from a heavy, spiral-wound paper tube. That’s pretty common for rockets up to H power, and it’s not uncommon for rockets up through K power. By the time you get to K power rockets, though, it’s a little more common to see body tubes made from plastic, fiberglass, or carbon fiber. Oddly, as you go up in power and size, body tubes often return to paper, where concrete forms like Sonotube are used!

Metric or Imperial Units?

In the discussion of airframe and motor mount sizes, we’ll use both metric and imperial units. You will see these systems of units used interchangeably throughout the book. Why not just stick with one or the other?

This is a book about rocket science, so I’d prefer to stick with the metric system and ignore imperial units. There are two reasons for not doing that, though. The first is that a lot of people who read this book will not be familiar with the metric system. Quick: how big is a 34 mm tube? Oh, about 1 1/3 of an inch… I’ve used the metric system professionally for years, but I still visualize 1 1/3 of an inch better than 34 mm.

The other reason is that there is no standard within model rocketry. When you order parts or read articles you’ll see people switching back and forth between metric and imperial units with dizzying frequency. You’ll see people talking about their 3-foot-long 29 mm rocket (the motor mount diameter) that reached 5,000 feet altitude. The motor might have 156 newton-seconds of total impulse (a metric unit), with a maximum thrust of 35 pounds. Since you’re going to see this constantly, you might as well get used to it here.

This book takes a pragmatic approach, embracing the schizophrenic nature of measurement in the United States by freely switching between metric and imperial. For the most part, I’ll stick with the units I see used most often in high-power rocketry, occasionally giving both units when you might see both in articles and reference sheets. Your calculator no doubt has conversions between the various units. It’s how measurement is done in the real world, so you might as well get used to it.

Body tubes sizes are usually specified by the inside diameter of the tube. Both metric and imperial units are used, for two reasons. First, body tubes sold as motor mounts are sized in millimeters, since motors are almost always listed by their diameter in millimeters. Second, body tubes sold as rocket airframes are usually given in inches, since people in the United States visualize inches better than millimeters. LOC Precision follows this trend. Airframes are listed with inside diameters in inches. The slightly thicker and more heat-resistant motor mount tubes are listed with the inside diameter in millimeters.

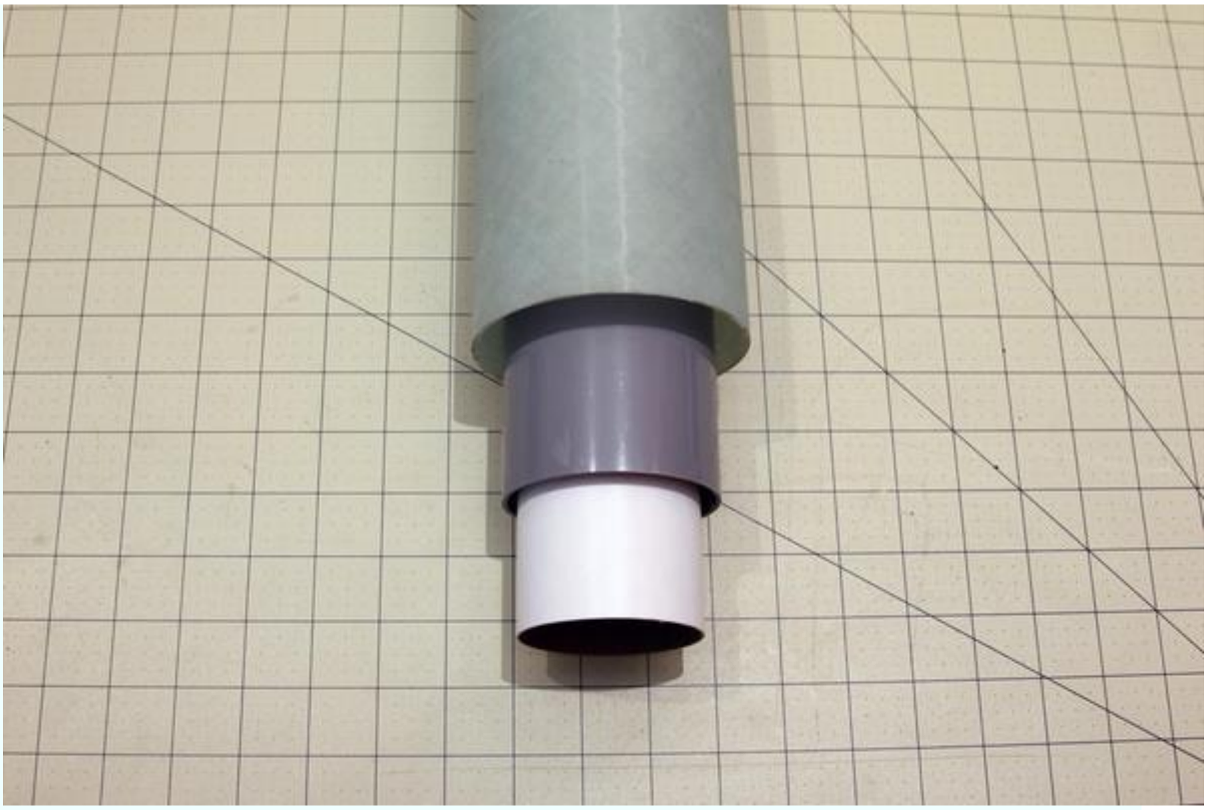


Figure 3-2. Body tubes for high-power rockets are typically made from heavy paper, plastic, fiberglass, or carbon fiber. Shown here, from smallest to largest, are paper, plastic, and fiberglass body tubes.

Table 3-3 shows the sizes for LOC Precision airframe tubes and motor mounts. Airframe tubes are made from heavy, spiral-wound paper. Motor mount tubes are also paper, but much heavier. The sizes are pretty typical compared to other manufacturers, although a few have much larger tubes, too.

Diameter (in)	Diameter (mm)	Use
1.52	39	Airframe
2.14	54	Airframe
2.56	65	Airframe
3.00	76	Airframe

Diameter (in)	**Diameter (mm)**	**Use**
3.90	99	Airframe
5.38	137	Airframe
7.51	191	Airframe
0.71	18	Motor mount
0.94	24	Motor mount
1.14	29	Motor mount
1.50	38	Motor mount
2.13	54	Motor mount
2.95	75	Motor mount
3.86	98	Motor mount

Table 3-3. LOC Precision tube sizes

Even when the diameter of an airframe tube or motor mount is given in millimeters, though, the length is virtually always given in inches. I know the confusion this causes, and I sympathize. That's just the way it's done.

The airframe for Callisto is a LOC Precision 2.56" airframe tube. LOC Precision sells these tubes in a 30" length, and we'll use all 30 inches of the tube.

THE MOTOR RETAINER

Almost all high-power rocket motors are made with a flange on the aft end that is too large to slide into the motor mount tube. That keeps the motor from pushing through the rocket during powered flight. We also need some way to keep the motor from falling out the back end, though. That's especially true when the ejection charge fires and the shock cord yanks hard on the rocket. The motor retainer is the part that keeps the motor firmly in place.

There are many styles of motor retainers. Most modern motor retainer are made up of a ring that is glued onto the motor mount tube, and a second ring that screws onto the first one, as we see in Figure 3-3. In the figure, the piece that is glued onto the motor mount tube is on top, while the piece that screws over the motor to fasten it in the motor tube is on the bottom.

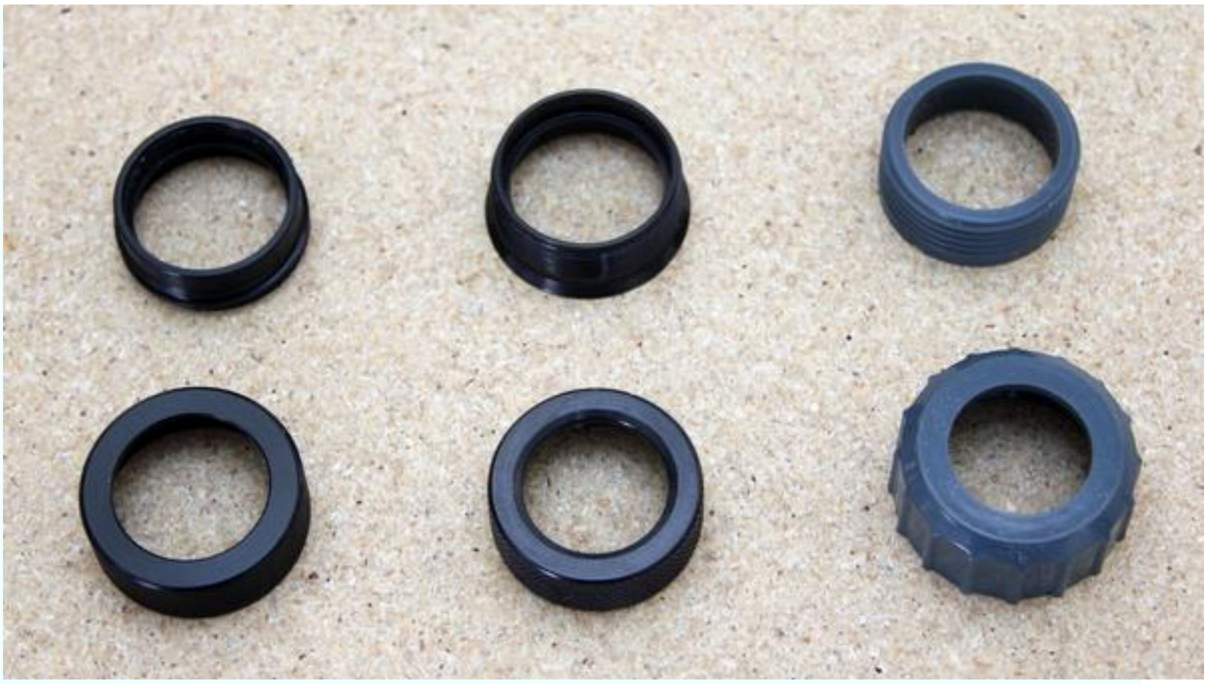


Figure 3-3. Here are a few examples of motor retainers from Aero Pack, PML, and Estes.

Motor tubes have pretty standard inside diameters, simply because the motors have very standard outside diameters. Motor mounts are made from a lot of materials, though, and the thicknesses of the materials vary a lot. The motor retainer slips over the outside of the motor mount tube, and as a result, there are a lot of different sizes of motor retainers. Aero Pack makes motor retainers for a wide variety of motor mount tubes, and they come in a similarly wide variety of sizes. You need to be sure to buy the right size for the motor mount you intend to use. An Aero Pack motor retainer is shown on the left in Figure 3-3.

There are a couple of ways to simplify the process of picking a motor retainer. LOC Precision carries Aero Pack motor retainers, but (naturally) only the ones that fit LOC Precision motor tubes. Buy the motor retainer when you order the parts for Callisto.

There are a few companies that make their own motor retainers. The center motor retainer in Figure 3-3 is made for PML motor mounts. The plastic one on the right is made by Estes Industries for their mid-power series, and it works great for 29 mm high-power rockets, too.

NOSE CONES

As shown in Figure 3-4, nose cones in high-power rockets are typically made from plastic, fiberglass, or carbon fiber, although I have also seen aluminum and wood used. Like most rockets that don’t exceed the speed of sound, Callisto’s nose cone is plastic.

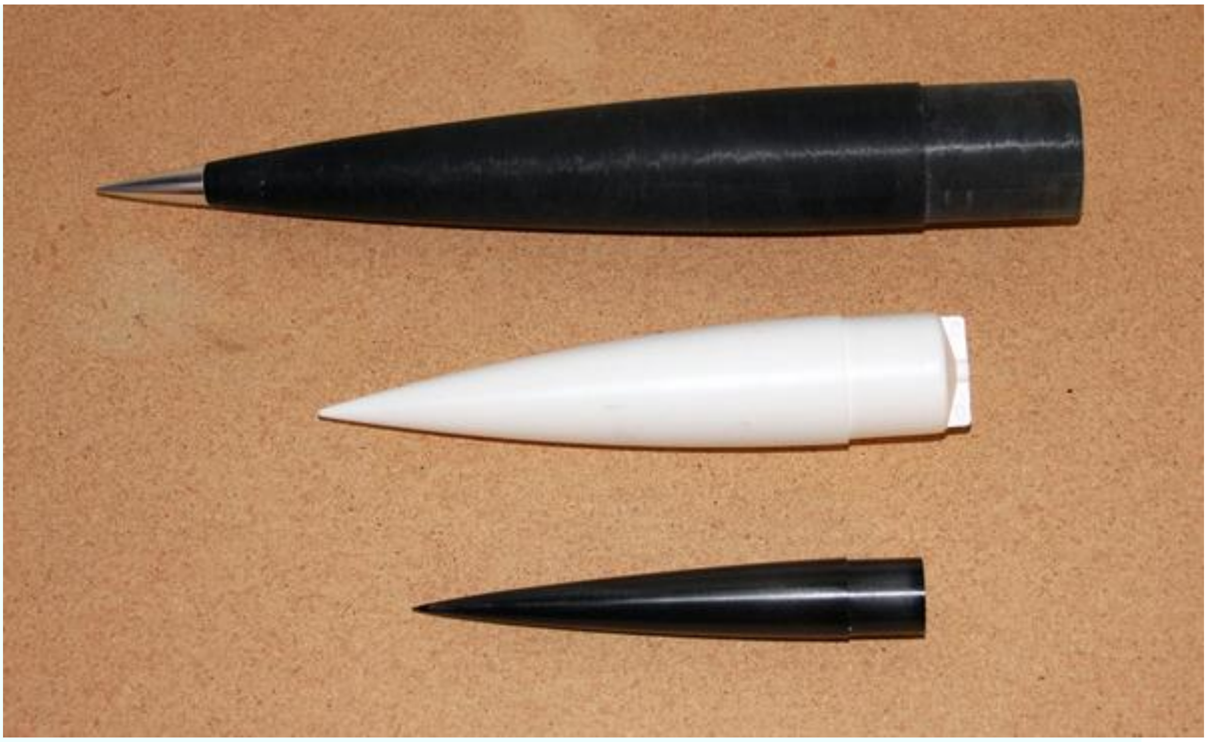


Figure 3-4. Nose cones are typically plastic, fiberglass, or carbon fiber. From top to bottom, a wound fiberglass nose cone with a metal tip, a molded plastic nose cone, and a molded fiberglass nose cone.

Fiberglass and Carbon Fiber Colors

You might have noticed that the fiberglass body tube in Figure 3-2 was green, while the fiberglass nose cone in Figure 3-4 is black. The body tube is from Public Missiles Ltd. (PML). Their fiberglass parts come in several colors, including the translucent green color shown. The nose cone is from Wildman

Rocketry; their fiberglass is currently black. There’s no real meaning to the colors; it’s just a dye added during manufacturing. Most of the G10 fiberglass parts tend to be green.

Carbon fiber parts look a lot like fiberglass, but are generally black. Carbon fiber weighs less than fiberglass for the same strength, but it is more expensive, and it also blocks radio waves from tracking equipment. Any transponder you put in your rocket won’t easily be able to get its signals out.

Fiberglass nose cones can be molded or spiral wound. When they are molded, they look a lot like plastic nose cones. Fiberglass and carbon fiber nose cones can also be spiral wound; when they are, they generally have a metal tip. There are two good reasons for using a metal tip. The first is that it’s easier to make the nose cone that way. The second is that the tip will heat up quicker than the rest of the nose cone, and for very fast rockets, heating is a problem. The aerodynamic heating of a fast rocket can melt the resin in fiberglass or carbon fiber, resulting in a fuzzy look where the fibers start to separate from the material and, eventually, structural failure. A metal tip delays this a bit. Keep in mind that a very fast rocket is not one ambling along at Mach 1.5 (that’s about 1,000 mph)—we’re talking about rockets that crack Mach 3 or so. None of the rockets in this book will reach Mach 3.

FINS

High-power rocket fins are usually made from plywood or fiberglass (see Figure 3-5). Plywood is used on smaller rockets (and large rockets that don’t fly particularly fast), while fiberglass fins are used for high-performance rockets or rockets that will exceed the speed of sound. While not as common, carbon fiber and molded plastic are also used.

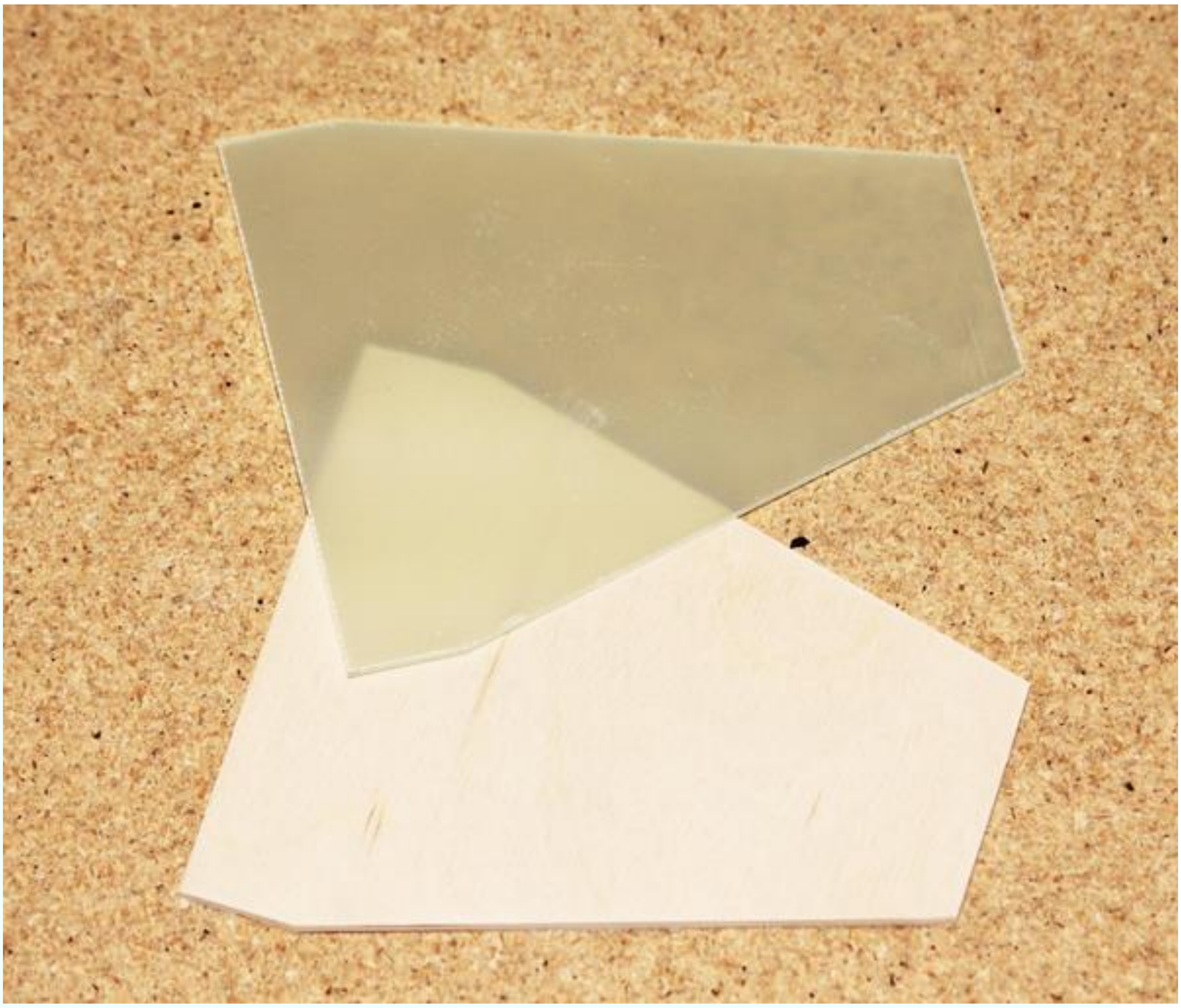


Figure 3-5. Fins are usually made from plywood or fiberglass.

Plywood fins are generally made from high-quality material called aircraft plywood, although thicker fins used in very large rockets might be made from common construction-grade plywood. Aircraft plywood is usually made from birch or mahogany, often with a core of basswood or poplar. Special heat- and moisture-resistant glues are used. You can find sheets of aircraft plywood at hobby stores, especially those specializing in model airplanes. It is also available online from most companies that sell parts for high-power rockets. Callisto's fins are made from 1/8"-thick aircraft plywood.

Fiberglass fins are usually made from G10 fiberglass. G10 refers to a specific type of fiberglass that is pressed and baked as it is made. It is known for high strength and low water absorption. G10 fins are thinner than plywood for the same strength, reducing the drag on the rocket.

CENTERING RINGS AND BULKHEADS

Centering rings and bulkheads are usually made from aircraft plywood or G10 fiberglass (see Figure 3-6). Centering rings are used to hold motor mounts inside the airframe tube. Bulkheads are used to block a tube completely, typically to form the bottom of a payload bay or the ends of an instrument bay in a dual-deploy rocket.

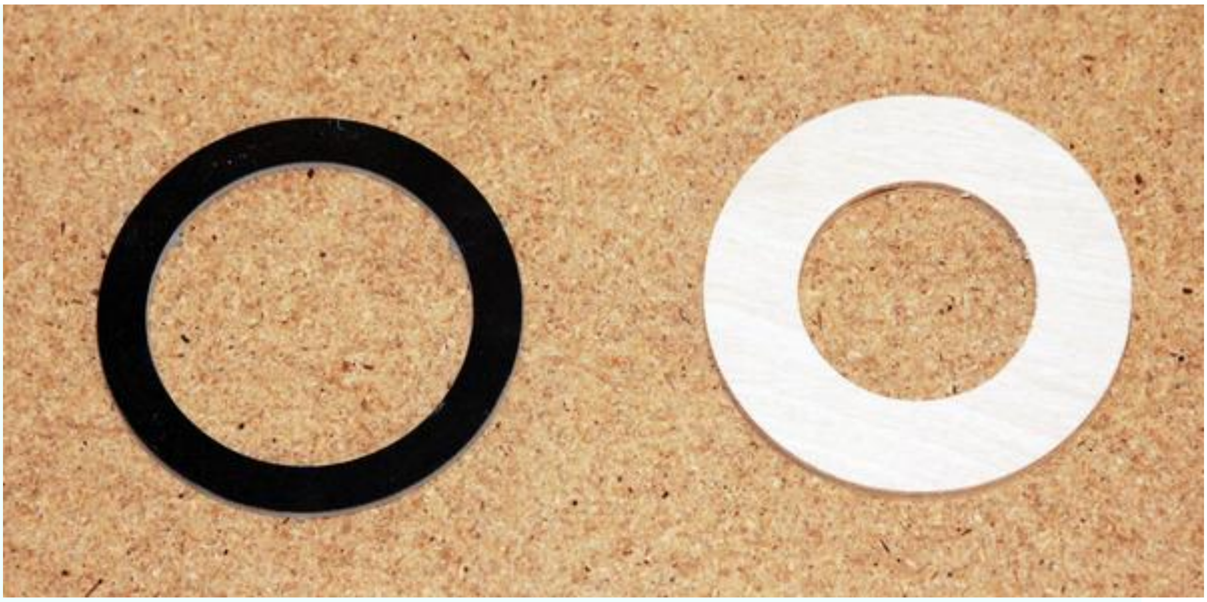


Figure 3-6. Centering rings are usually made from aircraft plywood or fiberglass.

Callisto uses 1/8”-thick aircraft plywood centering rings to hold the motor mount tube in the airframe, and a 1/8”-thick plate for the base of the payload bay.

EYE BOLTS

There is an eye bolt in Callisto that fastens to the bulkhead at the base of the payload bay. Like most eye bolts in small high-power rockets, this has a gap where the wire used to form the eye wraps around to the main shaft. Eye bolts that are forged, with no gap, are considerably stronger. Forged eye bolts are more popular in larger rockets because crash analysis of large rockets shows that one possible failure point is the eye bolt being ripped open.

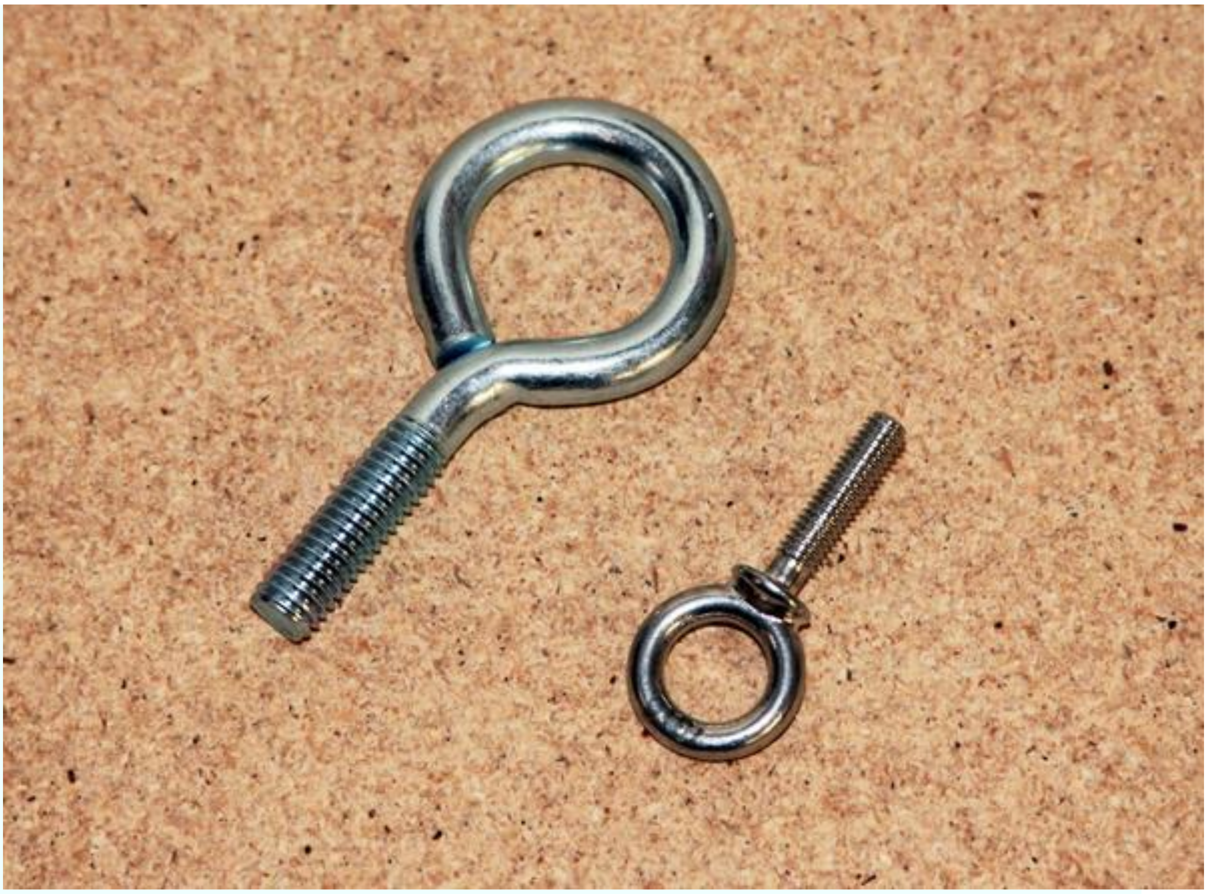


Figure 3-7. Eye bolts are used as attachment points for parachutes and shock cords.

Of course, there is no point in using a forged eye bolt that can withstand hundreds of pounds of force if it is bolted into a thin plywood bulkhead, which can't! Therefore, an open eye bolt is fine for Callisto.

LAUNCH LUGS AND RAIL BUTTONS

Launch lugs (Figure 3-8) are almost ubiquitous in low-power rocketry, and they are still quite common in mid-power and small high-power rockets. You can easily fly Callisto from a 1/4" launch rod. Figure 3-9shows Callisto taking off from the Mono Launcher, a launcher designed for low-power rockets. You can find complete plans for the Mono Launcher in *Make: Rockets*.

Launch lugs for small high-power rockets are made from reinforced paper, brass, or aluminum tubes. Figure 3-8 shows several of these. I like working with brass or aluminum launch lugs, so that's what the instructions for Callisto will show. You can substitute reinforced paper launch lugs like the ones LOC Precision sells, though.

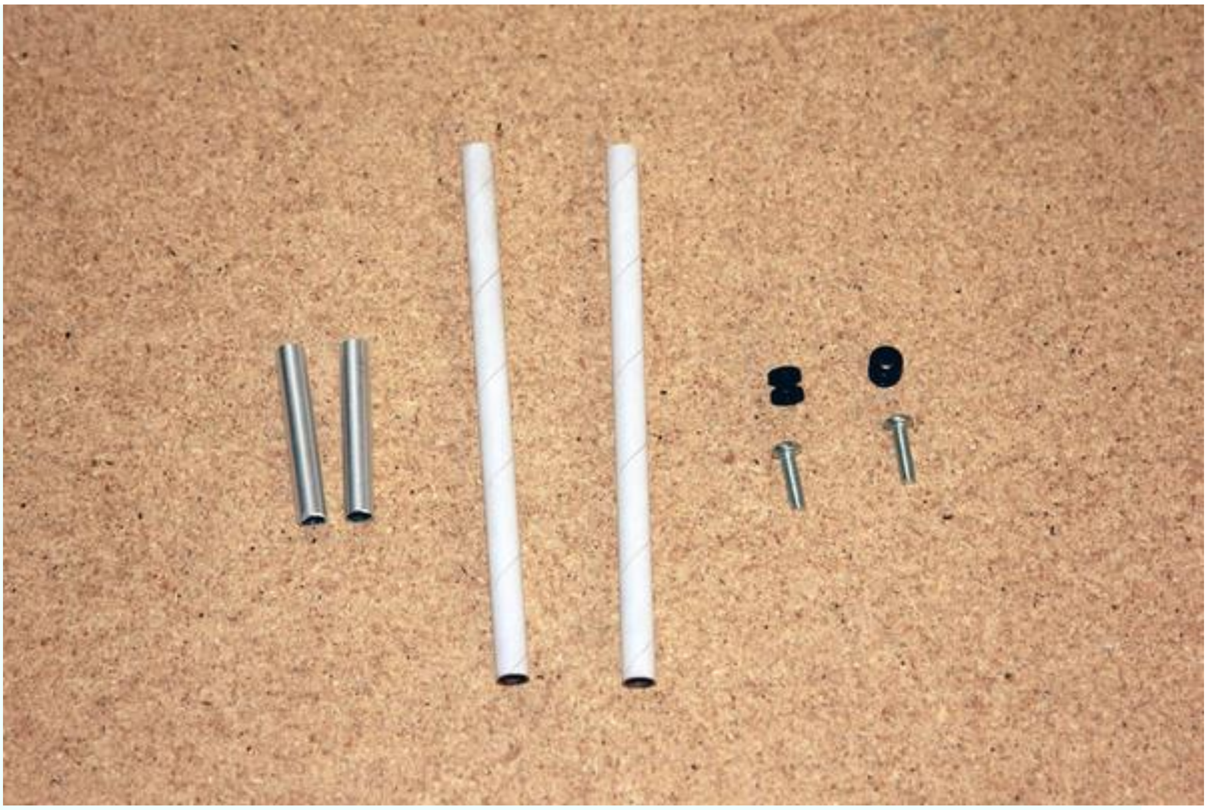


Figure 3-8. Launch lugs and rail buttons are used to guide the rocket in the first few feet of flight. This gives the rocket time to pick up speed so it is traveling fast enough for the fins to work.

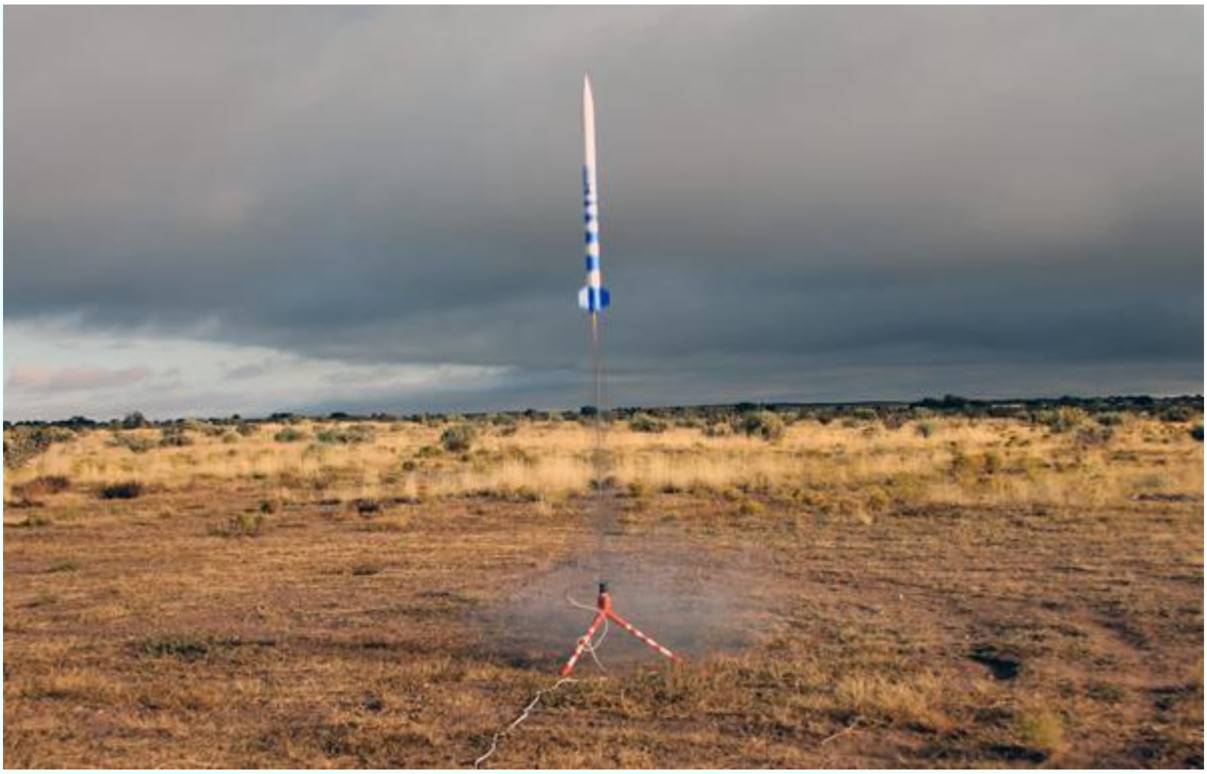


Figure 3-9. Callisto flies well from a sturdy low-power launcher with a 1/4" launch rod.

There are fundamental problems with launch rods as rockets get larger. The first of the two major problems is *rod whip*. To understand rod whip, take a long, thin piece of paper and run it quickly between your fingers. As the paper pulls through, the shortening end will start to flip back and forth. This happens with a launch rod, too. Even a thick 1/4" rod will whip back and forth enough to smack into the rocket if the launch rod is long enough or the rocket heavy enough. What we need is a more rigid launch rod.

This brings up the second problem with launch rods. Since the launch lug slips over the launch rod, you can't fasten anything to the launch rod to stiffen the rod. The only way to stiffen it is to use a prohibitively thick launch rod with large, heavy rockets.

Because of these issues, most high-power rockets are launched from launch rails. Figure 3-10 shows the end of a launch rail with a rail button slipped into the rail. Launch rails are stiffer than launch rods, so you don’t need one quite as large to hold up the rocket.

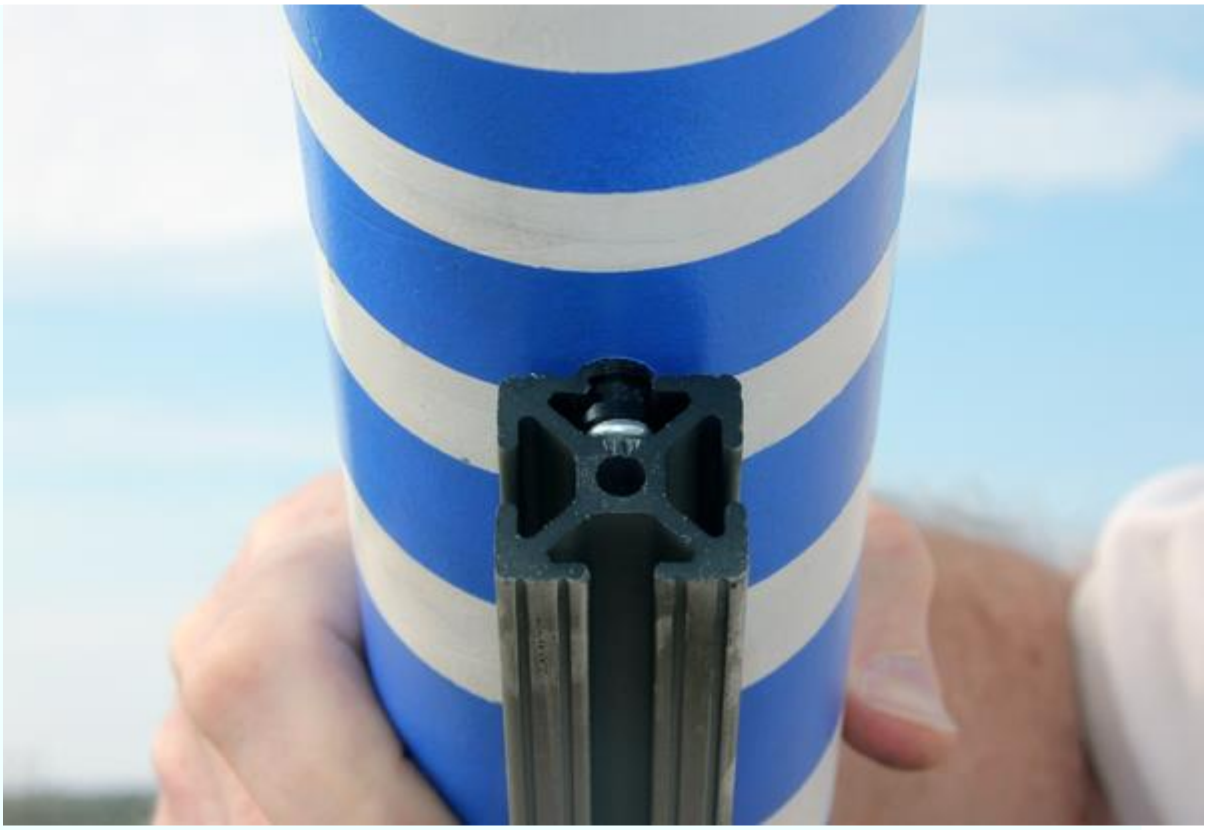


Figure 3-10. Rail buttons slip into the slot formed by a launch rail.

You can also add supports to the opposite side of the launch rail if needed. You’ll see that on larger launchers, like the one shown in Figure 3-11. This launcher uses a sturdy tower to steady the rocket. The rocket shown weighed almost 600 pounds, and was held rock steady by the launcher as it picked up speed.

There are two common sizes for launch rails, called 1010 and 1515, which refer to the sizes of the cross section of the rails: the 1010 rail is 1” x 1”, while the 1515 is 1 1/2” x 1 1/2”. LOC Precision sells two sizes of launch buttons, the series 1000 and series 1500, for these two sizes of launch rail. Callisto uses the smaller series 1000 launch buttons.

You can use launch lugs or launch buttons with Callisto. I used both. This gives me the option of flying Callisto from 1/4” launch rods on smaller launchers when I’m using F and G motors, but makes it easy to switch to a launch rail for an H motor when I’m using my club’s high-power launcher. While my club does have 1/4" launch rods for the high-power launcher, they are rarely used. Your club may be different. Check with the local custom if you don't want to use both launch lugs and rail buttons.

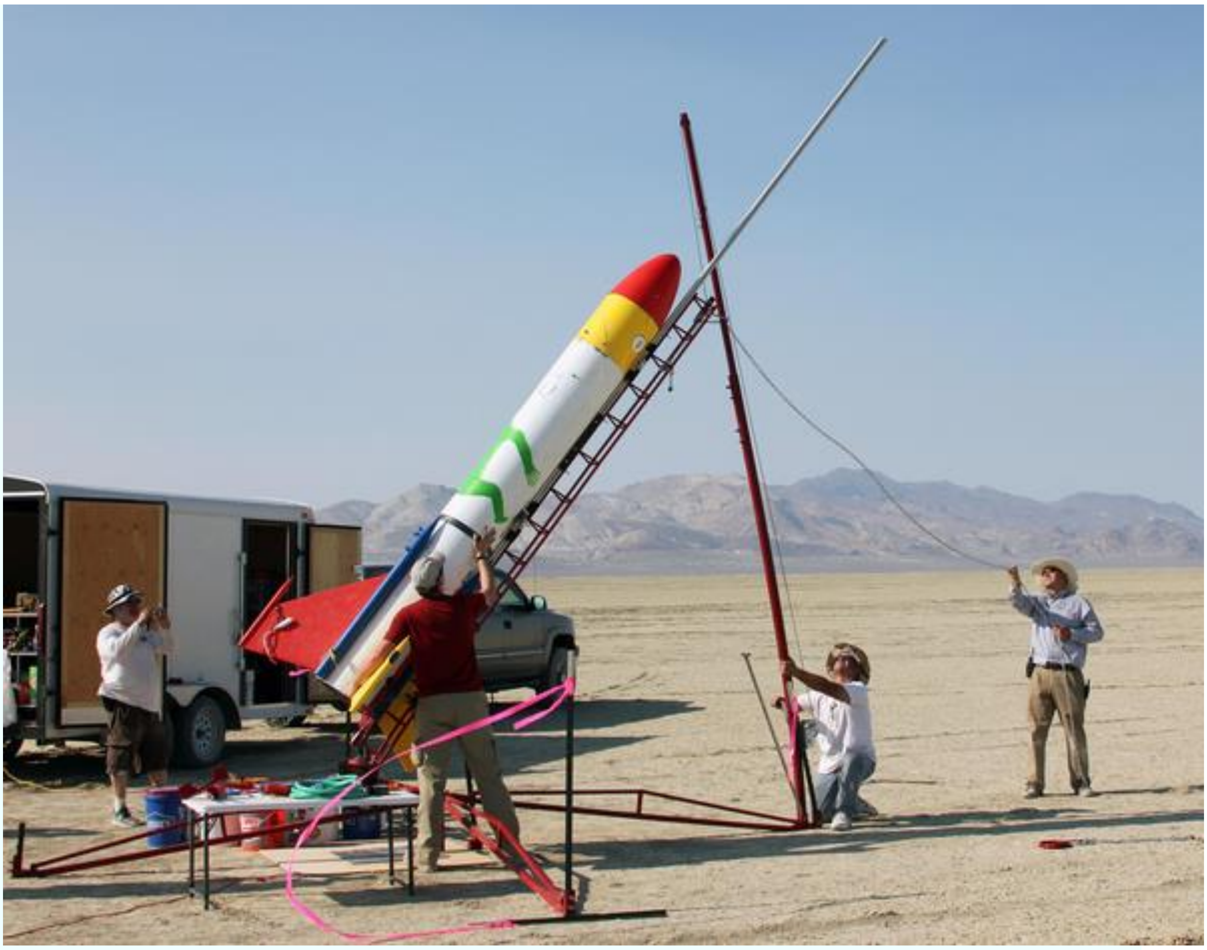


Figure 3-11. The Baby Q weighed nearly 600 pounds at liftoff, but was guided through its first moments of flight by this sturdy launcher using a launch rail reinforced with a steel tower.

PARACHUTE

Parachutes are almost always made from nylon. Note that the Public Missiles Ltd. (PML) parachute in Figure 3-12 has a hole in the middle, making it appear a little smaller than the LOC Precision parachute. This hole increases the stability of the parachute. We'll return to this in Chapter 9.

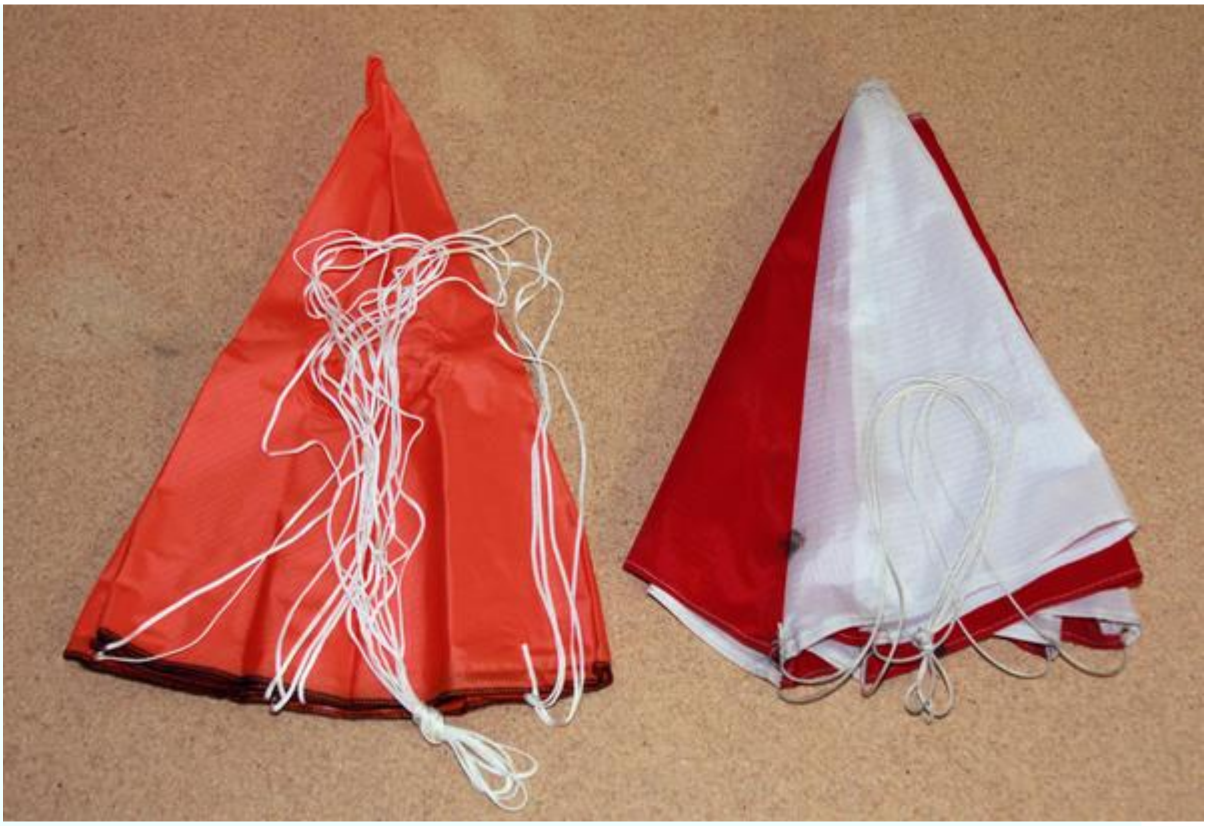


Figure 3-12. Shown here are 36”-diameter parachutes from LOC Precision and Public Missiles Ltd.

Callisto flies nicely on a 36” parachute. While it’s possible to make your own, I’d suggest buying one when you buy the other rocket parts. Parachutes are pretty cheap compared to the work it takes to make a good one.

We’ll return to the topic of parachutes in Chapter 9, when we’ll look at the various kinds of ‘chutes in more detail. We’ll also cover how to select an appropriately sized parachute for your rocket.

SHOCK CORD

The shock cord is used to attach the rocket booster, payload, or nose cone, and the parachute. Smaller shock cords are generally made from braided nylon straps, while shock cords for heavier rockets are generally tubular nylon (see Figure 3-13). These materials can hold anywhere from about 600 pounds to 3,000 pounds, depending on the size of the strap! Some fliers also use Kevlar shock cords, which are a bit more expensive, but resist heat from the ejection gases well.

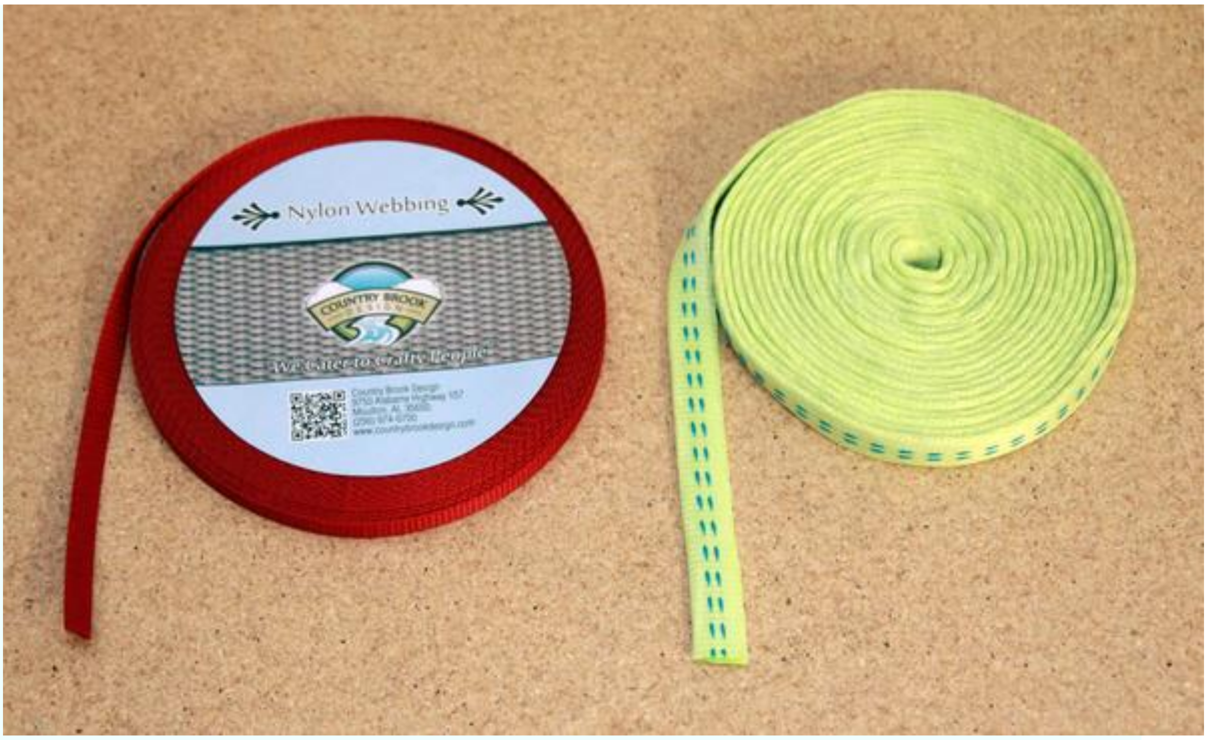


Figure 3-13. Shock cords are typically made from braided nylon or tubular nylon.

In general, shock cords should be three to five times the length of the rocket. If they are too short, the shock cord will stop the motion of the pieces of the rocket too soon after the ejection charge pushes them apart, possibly ripping the rocket apart or snapping the pieces back together, damaging the rocket. A shock cord really can’t be too long, but it does take up space and add weight.

Callisto is built with a shock cord made from 3/8” braided nylon purchased from Country Brook Design, a craft company that sells braided and tubular nylon in a wide variety of colors. LOC Precision sells tubular nylon that will work well, too. Other rocket vendors invariably carry either tubular nylon or braided nylon. The smaller thicknesses that handle 600 pounds or so are fine for Callisto, but heavier-weight shock cords will work, too. Get one at least 12 feet long; 16–20 feet is better.

RECOVERY BLANKET

Recovery blankets are made from flame-resistant cloth (see Figure 3-14). They sit between the parachute and the hot gases of the ejection charge. You can make your own from a variety of materials or buy one when ordering the other parts for your rocket.

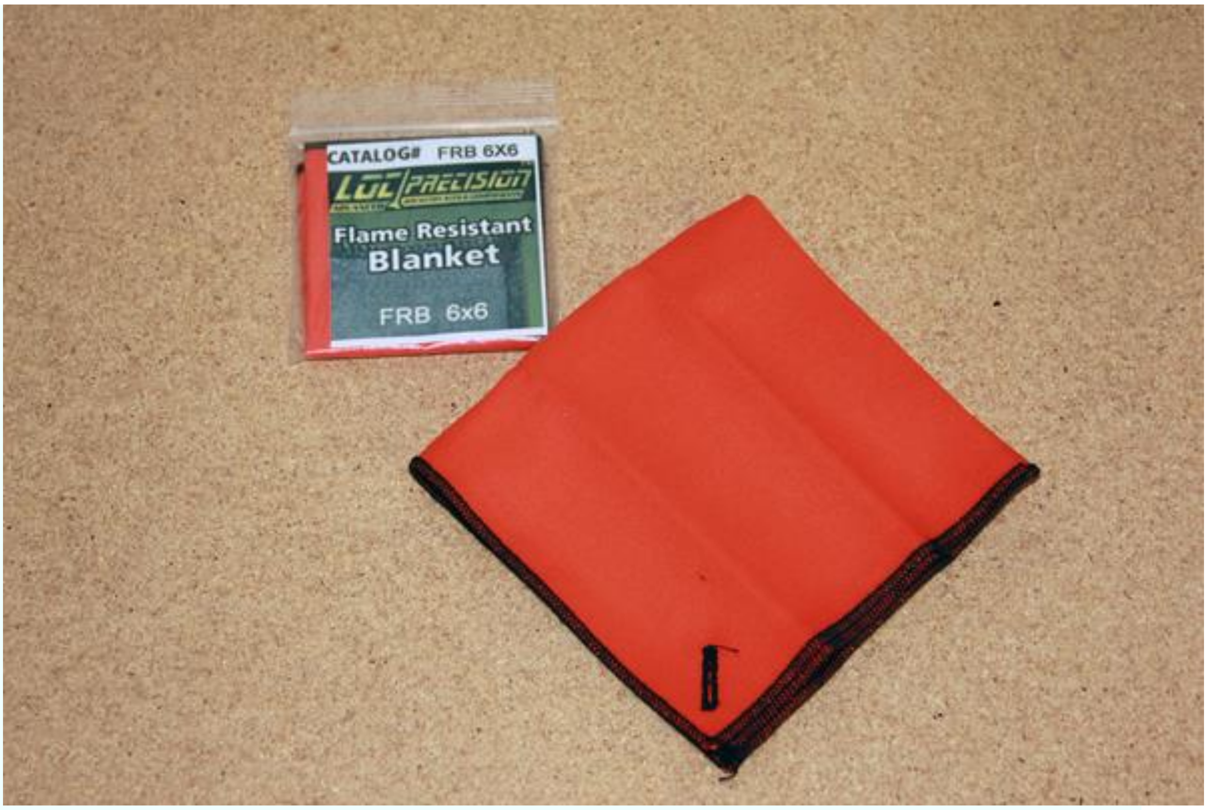


Figure 3-14. Flame-resistant recovery blankets are used to protect the parachute from the ejection charge.

For a square blanket, get one with sides about three times larger than the diameter of the airframe tube. A bit larger doesn't hurt, but if the blanket is any smaller, there is a real danger of scorching the parachute.

The biggest problem with making your own is finding the material—unless you get creative. You want Nomex or Kevlar cloth, or something similar. This is tough to find in small quantities, but may be available from some unexpected sources. One member of my rocket club uses fabric from a surplus Kevlar bulletproof vest.

If you've flown low-power rockets, you might be familiar with recovery wadding or dog barf. They serve the same purpose as a recovery blanket, but don't tend to work as well in very large airframe tubes and with the stronger ejection charges used in high-power rockets. You could probably get by with recovery wadding with Callisto, but I would not recommend it.

There are other ways to protect the parachute. Public Missiles Ltd. champions the use of a piston ejection system in its kits; this system uses a sliding piston that sits between the parachute and most of the shock cord. Some people have used baffles successfully, preventing the hot gases from shooting straight into the delicate parachute. We'll explore a recovery method known as dual deploy in Chapters 7 and 8, though, and that puts a real strain on pistons or baffles, especially in a rocket that might use a standard ejection charge with certain motors and dual deploy on certain other flights.

SHOCK CORD SLEEVE

Most of the shock cord is packed on the other side of the recovery blanket from the ejection charge, and is protected by the recovery blanket. The section right next to the motor will get a blast from the ejection charge as the parachute and recovery blanket slide out of the rocket. This is not severe enough to cause immediate damage, but it will add up over time, gradually weakening the shock cord.

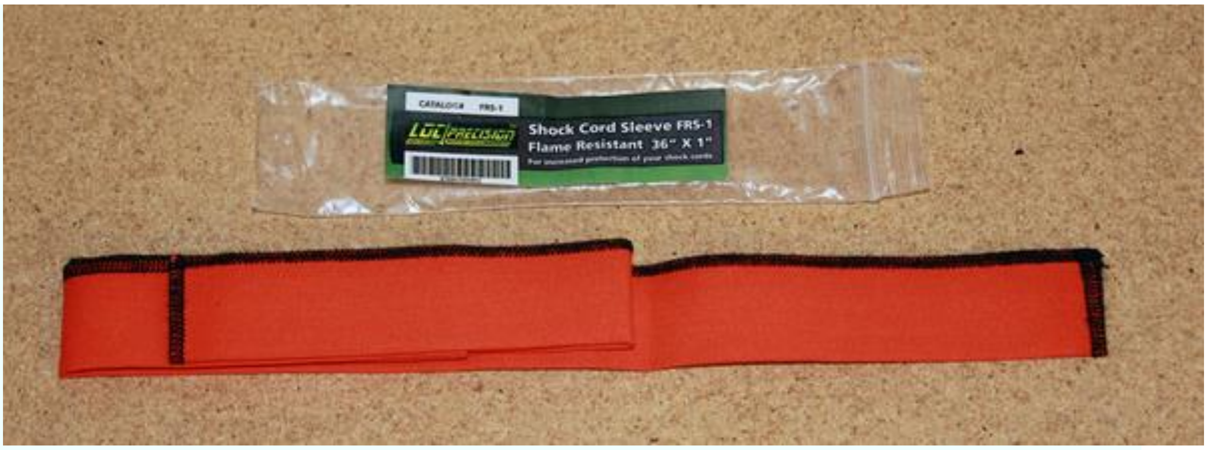


Figure 3-15. The shock cord sleeve protects the shock cord from the ejection charge.

The solution is to cover the lower part of the shock cord with a Nomex or Kevlar sleeve, like the one made by LOC Precision that is shown in Figure 3-15. This protects the most delicate part of the shock cord. There are other alternatives, too. One is a tube of Kevlar fabric, which we'll try in Chapter 6. Another is using a steel cable for the lower part of the shock cord.

QUICK LINKS

A quick link is a link from a chain that has a threaded sleeve allowing the link to be opened (Figure 3-16). We use them in high-power rocketry to attach the shock cord to parachutes, recovery blankets, payload bays, and so forth. They come in a variety of sizes and strengths. The size is usually given based on the diameter of the rod used to form the link itself. Callisto is a fairly light rocket; any quick link 1/8” or thicker should work. Put another way, look for a quick link that will hold at least 200 lb.

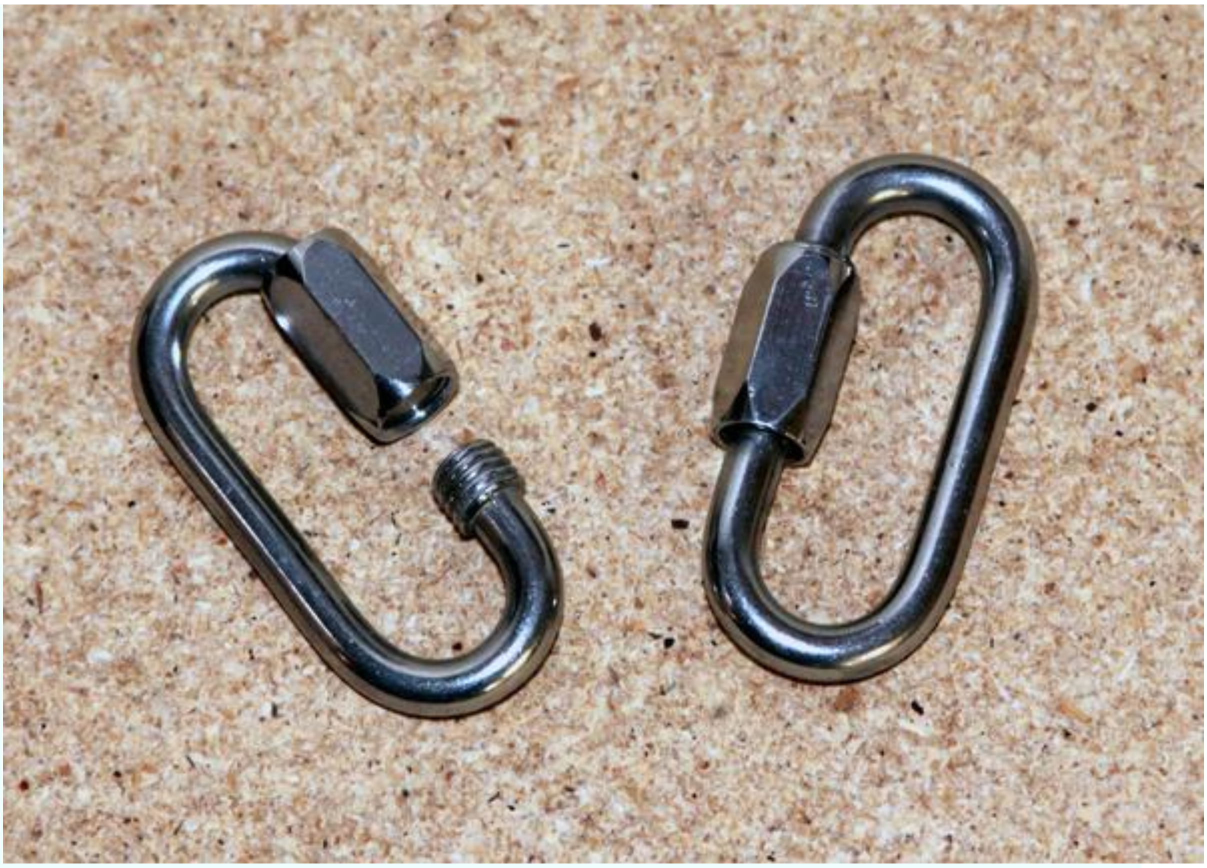


Figure 3-16. Quick links are used to attach shock cords to parachutes and the rocket.

The other factor to consider is the size of the opening with the sleeve fully opened, because you need to make sure the open quick link will fit over the eye bolt at the base of the payload bay. The smaller quick links like the 1/8” Blue Hawk quick link you can likely find at your local hardware store will work just fine with the eye bolt that LOC Precision ships with its payload bay kit. If you use some other eye bolt, measure the thickness of the rod used to form the bolt, or just take it with you and give it a try at the hardware store.

A Detailed Walk-Through of the Tools and Supplies

You will need some basic tools to build the rockets in this book. You can get by with a fairly small number of inexpensive tools, but you can also get good use out of sophisticated shop tools. We’re going to take a tour of some of those tools in this section.

Before we get going, though, there are two things to keep in mind. If you are patient, you can build Callisto with wood glue, a hobby knife, and any small saw (even a keyhole saw attached to your hobby knife). You can build almost anything in this book if you add a Dremel tool with a set of cutting blades and a hand drill.

Of course, it’s a lot easier with additional tools. Some of the tools shown here I don’t actually own myself, because I don’t use them often enough to justify the cost. If you are lucky enough to live in a city with one of the rapidly growing number of community shops, though, you can probably get access to everything shown here, and more, for a modest monthly fee. In some areas, the shops are even free. These are often called *makerspaces*, *hackerspaces*, or *fablabs*. They are places where people interested in do-it-yourself projects meet and share tools, offer classes, and even work on collaborative projects. Try a web search for one of these words with the name of your city or town. For example, a search for “makerspaces Albuquerque” turned up Quelab, the local makerspace where I’m a member. They have all of the tools shown here and more.

HOBBY KNIFE

Many of the materials used to build high-power rockets can be cut with a hobby knife. Take a look around the store when you pick one up. There are many different kinds of blades. I tend to use the standard blade, keyhole saw, and a flat scraper more than anything else. You can see these in Figure 3-17.

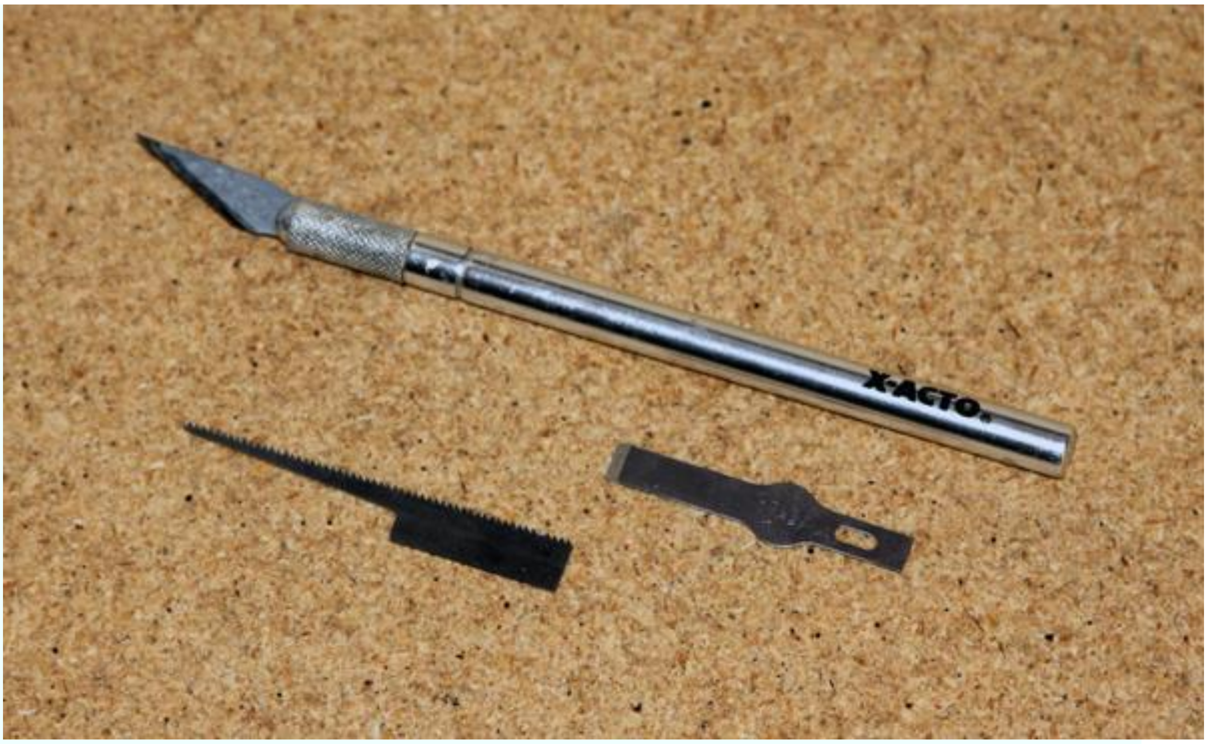


Figure 3-17. A hobby knife is essential. A nice set is very handy. Shown here are a standard #11 blade in the knife handle, a keyhole saw blade, and a scraper blade.

Hobby knives are available at almost any hardware store or hobby store.

DREMEL TOOL

There are a few things, like fiberglass body tubes and small pieces of metal, that a hobby knife doesn’t cut very well. That’s where a Dremel tool comes in handy (see Figure 3-18). These motorized hand tools have cutting blades that I’m tempted to say can handle anything you need to handle in this book. (I would say that, except I definitely used other saws myself.)

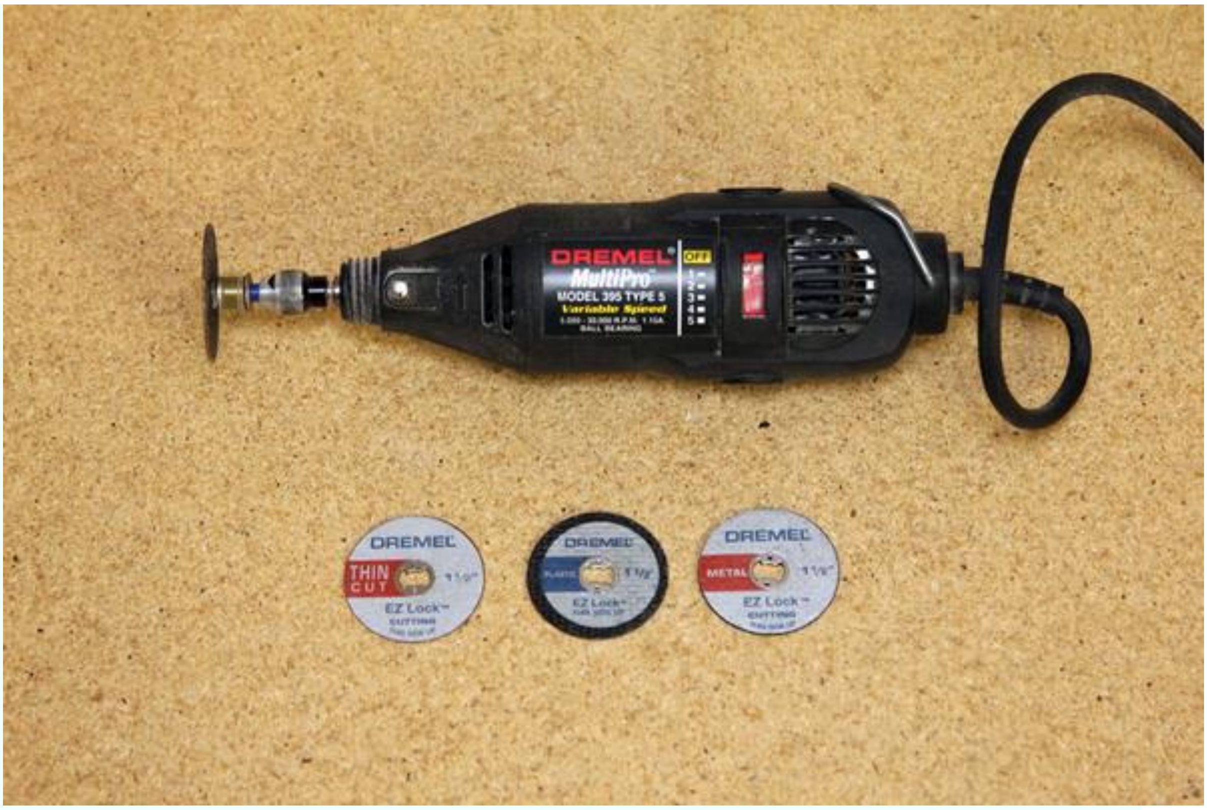


Figure 3-18. Dremel tools can cut pretty much anything the hobby knife cannot.

Cutting wheels differ depending on what they are designed to cut. Be sure you get cutting wheels for both plastic and metal.

OTHER SAWS

There are a lot of other saws that are handy when building rockets. I wouldn't run right out and buy any of these just for rockets—at least, not yet—but they are certainly handy.

The first is a band saw (Figure 3-19). It's a great general-purpose saw for quick cuts. It can handle gentle curved cuts, and with the right blade can cut wood, fiberglass, or soft metals like brass and aluminum.

Figure 3-19. Pretty much any kind of saw will be useful at some point when building rockets. Pictured here is a band saw.

Some sort of cutoff saw is very useful too. These typically have a thin cutting wheel, although some have saw blades. I use one for metal rods and body tubes.

I’ve also used scroll saws, hacksaws, table saws, and jab saws from time to time. If you have a saw in your shop, you’ll probably end up using it at some point when building rockets.

DRILL

This may surprise you, but there are a lot of holes in a high-power rocket, especially once you start building rockets larger than Callisto. You don’t need a drill for Callisto, but you will definitely need one for Deimos, the Level 2 rocket we’ll build in Chapter 6.

If you are only going to buy one drill, get a small hand drill. It will work fine for any hole you need to drill for the rockets in this book. Some rockets, especially larger ones, just don't fit into a drill press. Only a hand drill will work in those situations. If you have a drill press, though, you'll use it a lot. A drill press is great for drilling nice, vertical holes, and I use mine far more often than I use my hand drill (Figure 3-20).

RYOBI
RYOBI
DEWALT
DEWALT
18v

Figure 3-20. You will need some way to drill holes.

GLUE

Most high-power rockets are almost entirely held together with glue, and almost all of them are glued with some kind of epoxy resin glue. There are exceptions, and your Callisto could be one of them. It’s made from paper and wood, which bond quite nicely with wood glue. We’ll discuss both alternatives when building the rocket. Figure 3-21 shows an assortment of glues and materials for working with the glue.

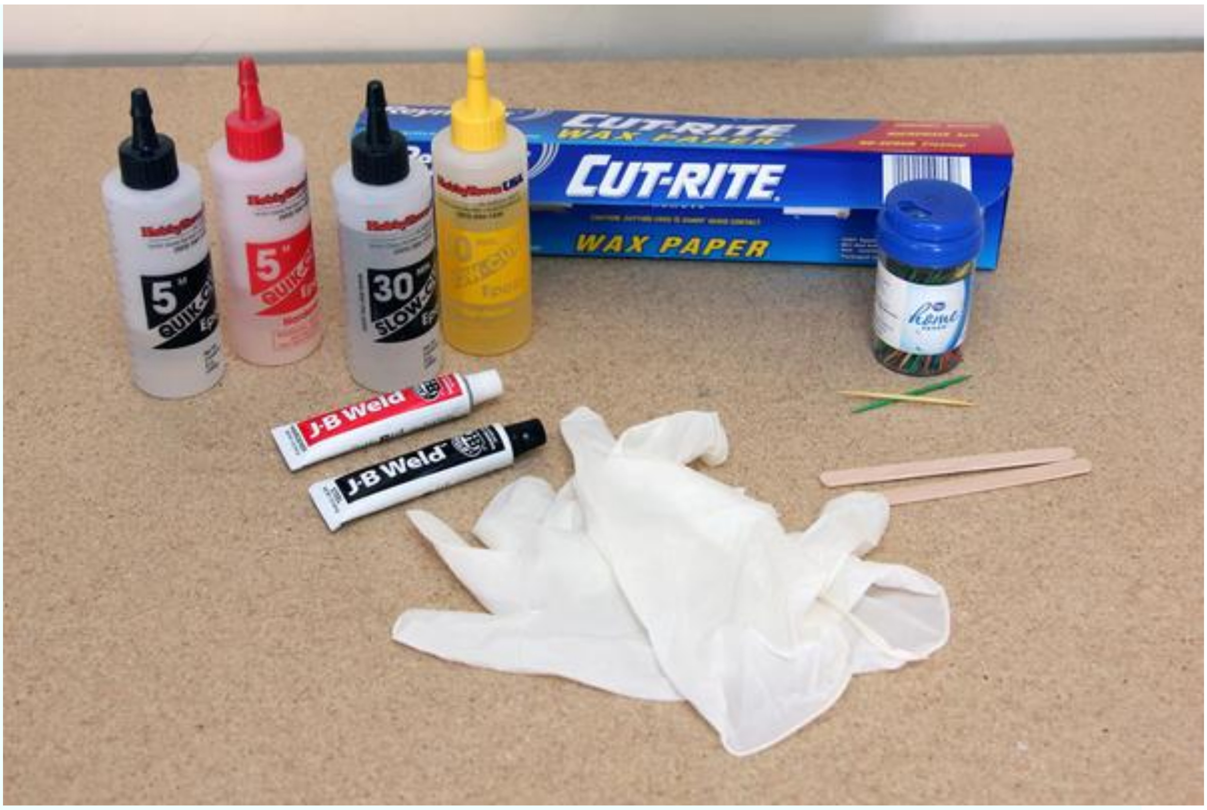


Figure 3-21. Most high-power rockets are built with epoxy glue, but paper and wood rockets like Callisto can also be built using wood glue.

Personally, though, I used epoxy to build Callisto. You will use a lot of epoxy, so don’t buy the tiny tubes that are intended for quick repairs. You should get the bottles that have a combined volume of 9 oz or so (available at hobby stores, or you can order online). You will need a fast-curing, 5-minute epoxy as well as a slow-curing, 30-minute one.

You will also need a small amount of heat-resistant epoxy. JB Weld is a popular brand name for heat-resistant epoxy. Small tubes of JB Weld are fine, since you only need this specialized glue right around the motor mount.

The big disadvantage to epoxy is that it is a dermal irritant in its uncured state. Lots of people get it on their skin without thinking too much about it, but that’s a really bad idea. You can develop a severe allergy through careless exposure to epoxy. One rocket scientist I know used his fingers to smear epoxy on rockets for years. He has an allergy now that is so severe he missed several days of work after being exposed to epoxy during a fiberglassing session. You should buy a box of disposable gloves and wear them any time you are working with epoxy.

You will also need a place to mix glue and something to apply it with. I generally use wax paper for mixing glue, and popsicle sticks or toothpicks to apply the glue. You can find popsicle sticks at most hobby and craft stores.

SANDPAPER

Sandpaper comes in a wide variety of kinds. It’s rated by grit, which indicates the size of the particles used in the sandpaper. The bigger the number, the smaller the particles and the smoother the sandpaper will be (Figure 3-22).

Figure 3-22. Get at least one medium grit sandpaper and one fine grit sandpaper.

Medium grit sandpaper is used to shape fins, remove burrs from plastic parts, and shape and size various parts of the rocket. A grit of 100 to 120 is about right.

Fine sandpaper is used to scuff surfaces before painting, smooth primer before painting, and remove scratch marks from heavy sanding. Get something in the 150–220 grit range.

SANDING BLOCK

A lot of the surfaces on a rocket are large, flat surfaces that need to stay that way. Others, like airfoils, need to be flat along one axis. Using just finger pressure, you can easily sand small grooves into a flat fin. A sanding block holds the sandpaper flat, applying even pressure across the area being sanded (Figure 3-23).

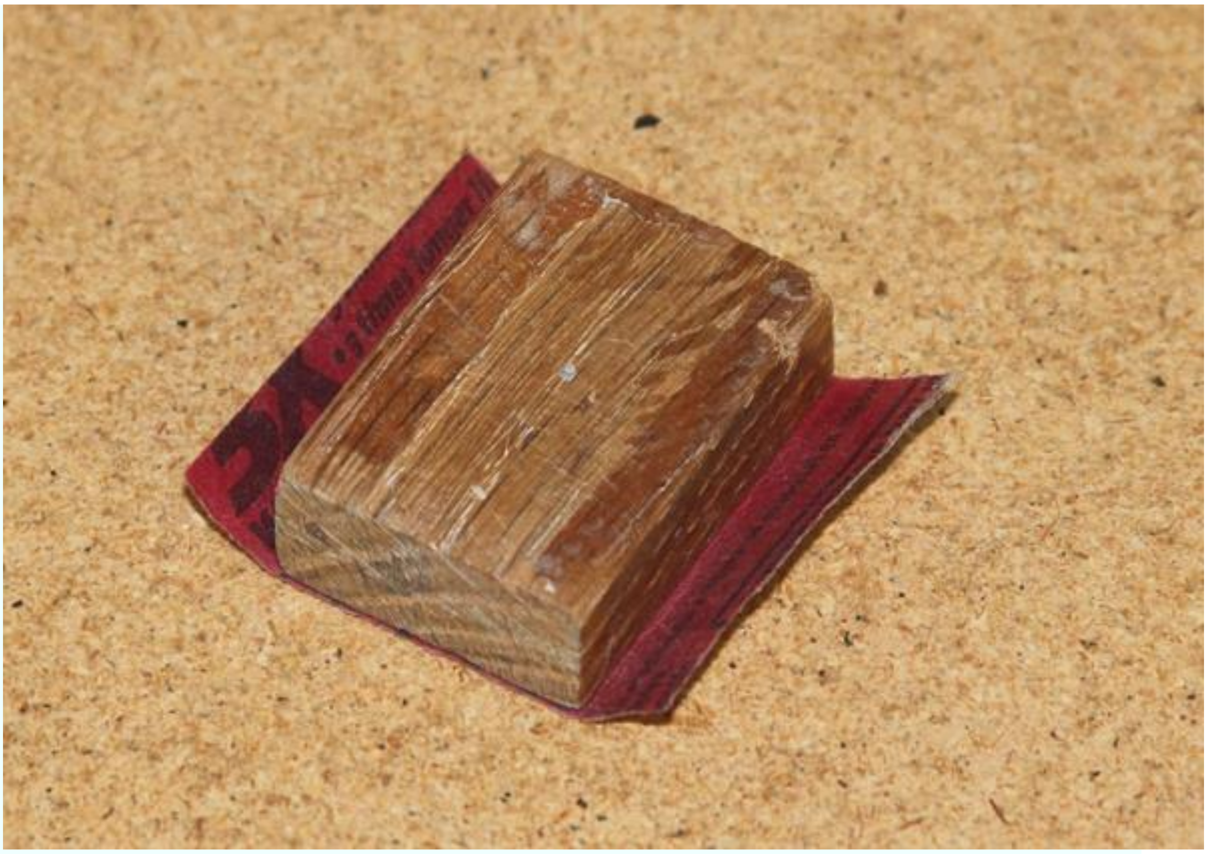


Figure 3-23. Use a sanding block to sand flat surfaces.

Sanding blocks don't have to be fancy. I've used a 0.75" x 1.5" x 2.25" piece of scrap wood for years. It's the perfect size for 1/16th of a sheet of sandpaper.

WOOD PRIMER

Wood is very porous. Paint applied directly to the wood will be quite rough. There are a number of wood fillers available, such as those shown in Figure 3-24, that prepare the wood for paint by creating a satin or glassy surface.

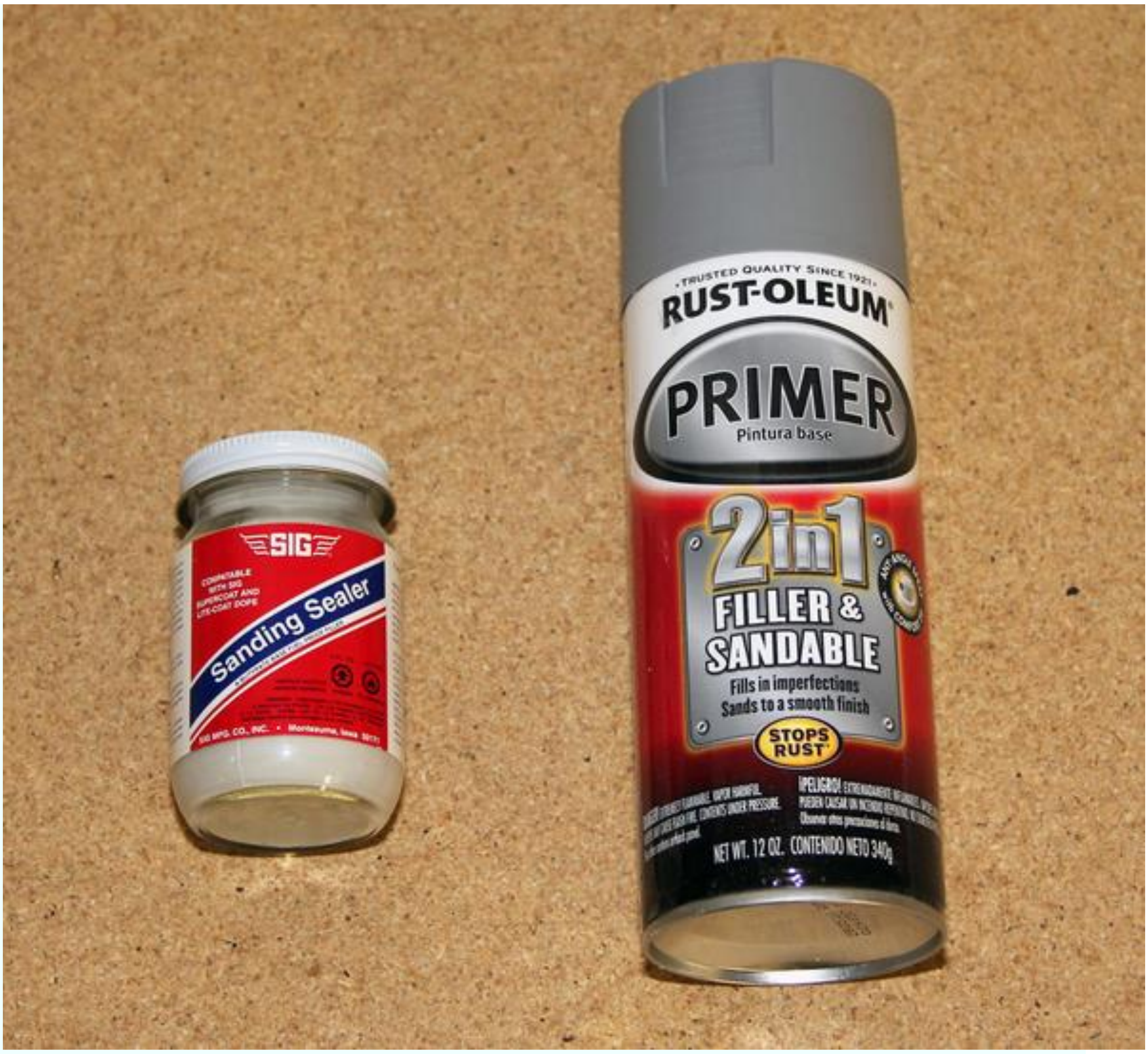


Figure 3-24. Use some form of filler to prepare the wood for paint.

Dry sandable filling primer works very well. Be sure to get a filling primer, not just a standard primer. While wet sandable primers will do, I prefer a dry sandable primer like Rust-Oleum 2in1 Filler & Sandable Primer. I occasionally find this at Lowe’s hardware store, but it’s often out of stock. It’s available from Amazon, too.

PAINT

Rockets should look cool. The only way to do that is with a good paint job. Almost any kind of paint that won’t dissolve in water once it is dry will do (see Figure 3-25).

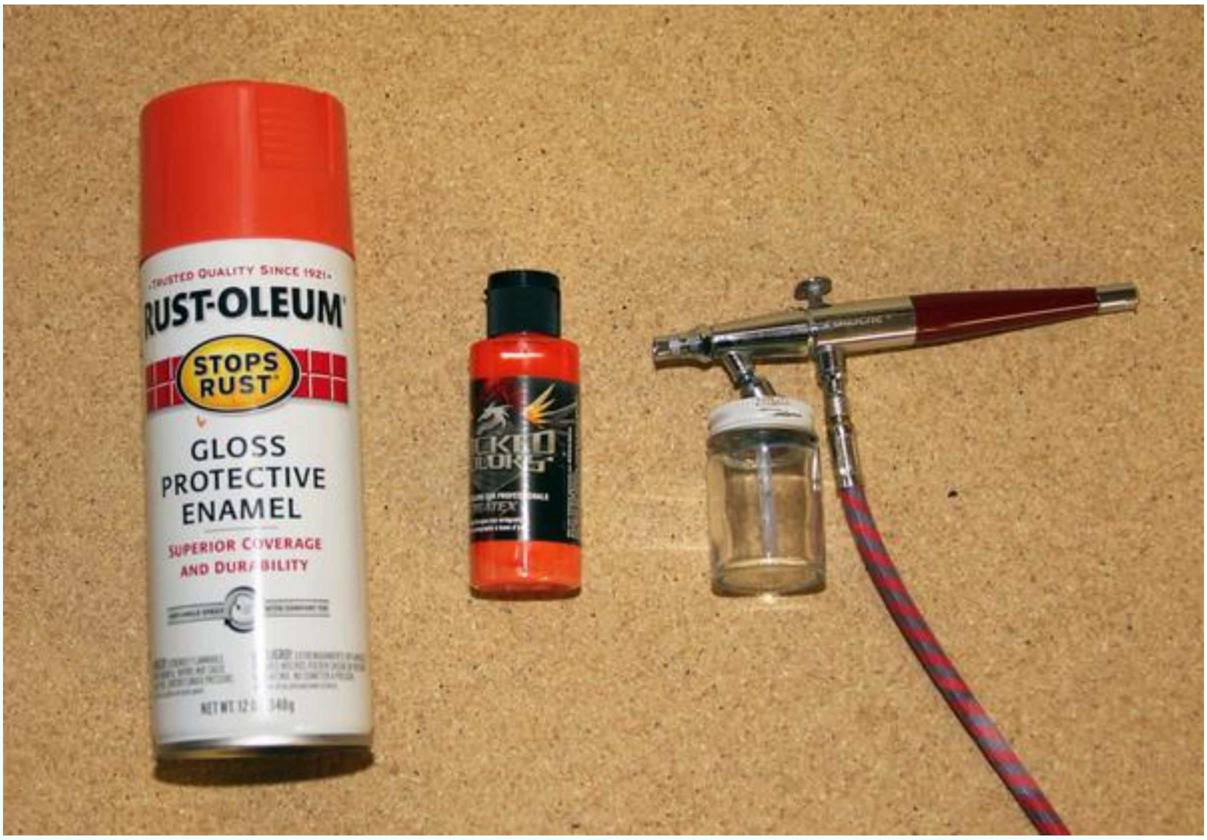


Figure 3-25. Use almost any kind of non-water-soluble paint.

I generally spray paint my rockets. If you spray paint your rockets, too, be sure to get a good brand of painter's tape. I have used both acrylic paint, usually with an airbrush, and enamel paint. Both work well.

You can also use paintbrushes if you prefer. A nice wide brush, 1/4" to 3/16" wide, works really well. Brush cleaner is also a must. Paint thinner for the kind of paint you are using works well. Acrylics are nice because you can clean the brush with water. Nail polish remover works fine to clean up enamel paint.

MISCELLANEOUS MATERIALS

You will use a lot of everyday items and other tools that you almost certainly have lying around the house, too. These include paper, pencils, scissors, rulers, a compass, a protractor, and corrugated cardboard. (You might need to hunt around for some of these. For example, do you have a 12" square piece of corrugated cardboard handy? You will need one—but a piece from the box your rocket parts arrive in will work just fine.)

Building the Rocket

With parts and tools assembled, it’s time to build a rocket!

Read all of the instructions before you begin building. I know. You hate directions. There is a reason you need to read these, though. If you follow through step by step, you will build a perfectly good rocket, then discover that there are some cool options you could have used—but it’s too late. Read through so you know what options you want *before* you start.

Cutting the Fins

Start by cutting three fins from 1/8” aircraft plywood (see Figure 3-26). You can use almost any kind of saw to do this. I used the laser cutter at my local makerspace to cut the fins shown in Figure 3-26, but a band saw, table saw, or a handsaw with fine teeth will do the job nicely. If you use a saw, though, be sure to sand the finished fins so all three fins are exactly the same size. It’s really not that important if one of the dimensions of the fin is off by 1/16” or so from what is shown in the plan, but if one fin is 1/16” larger than another, that could cause problems.

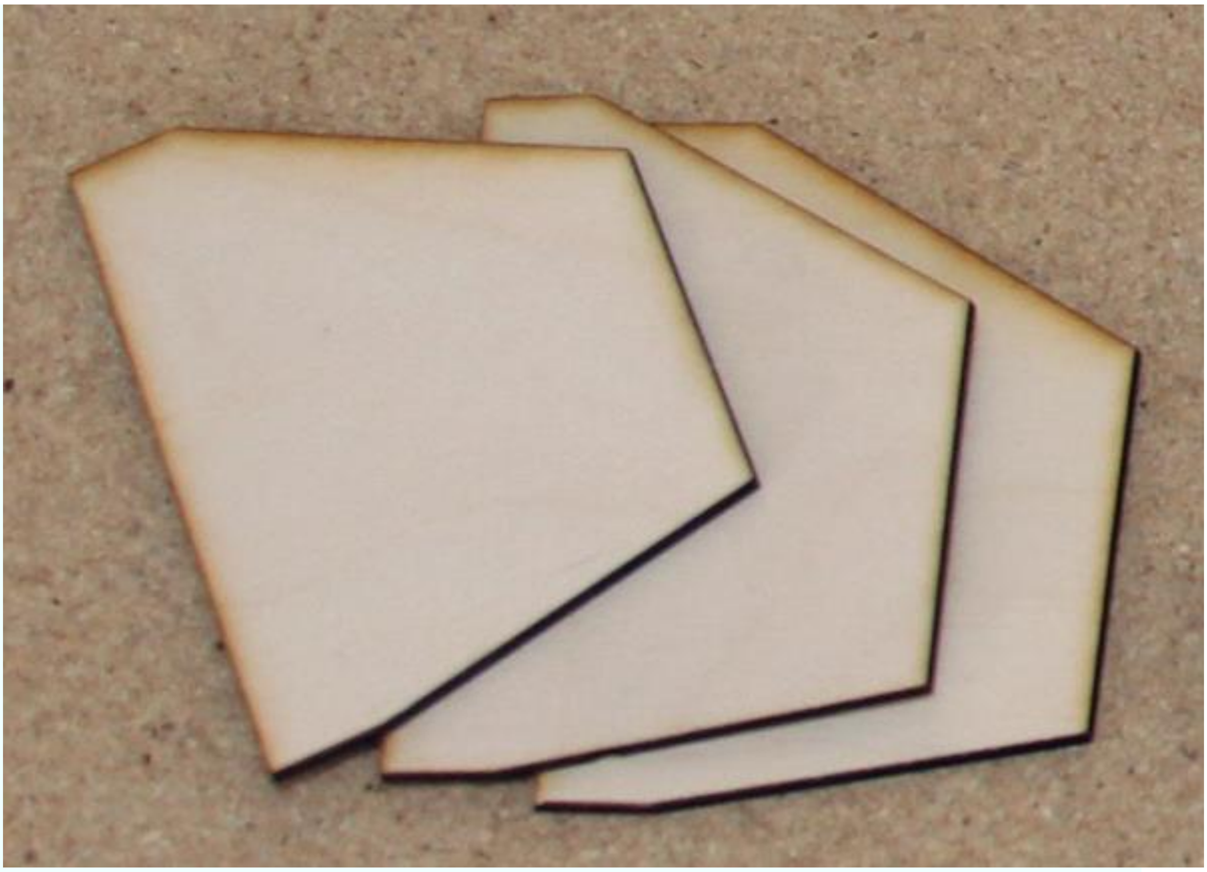


Figure 3-26. Cut three fins from 1/8” aircraft plywood.

The dimensions for the fins are in the simulation you created in Chapter 2. OpenRocket will print a full-size fin template, or you can work from the dimensions and create one with a ruler and pencil.

It’s not that important that the fins be exactly this shape. The rocket will fly fine as long as the fins have about the same area as the ones shown. You can sweep them back, round them off, or even sweep them forward. If you do make a change, go back to the simulator and make the change there, too. Make sure the stability number stays greater than 1 when the motors you expect to fly are installed. Bigger is better up to a point, but avoid really high stability numbers—say, over 4—unless you research this carefully and understand the disadvantages. The short version is you don’t want to fly a rocket with a high stability number in high wind.

Once the fins are cut, round the leading and trailing edges of the fins. You can do this with medium grit sandpaper and a sanding block. The outside edge can be rounded or sanded flat, but the root edge—the edge that will be glued to the motor mount—must be left flat.

CUTTING A FIN TEMPLATE

The next step is to cut a fin template. This is used both to mark the airframe tube to cut slots for the fins and to hold the fins securely while the initial application of glue hardens.

Cut a 12” square piece of corrugated cardboard, foam core, or a similar flat, rigid material. Draw lines from one corner to another, and then use a circle template or compass to draw a circle the same diameter as the outside of the airframe (see Figure 3-27). It’s best not to use the airframe itself, since the circle must be centered exactly on the crossed pencil marks at the center of the sheet.

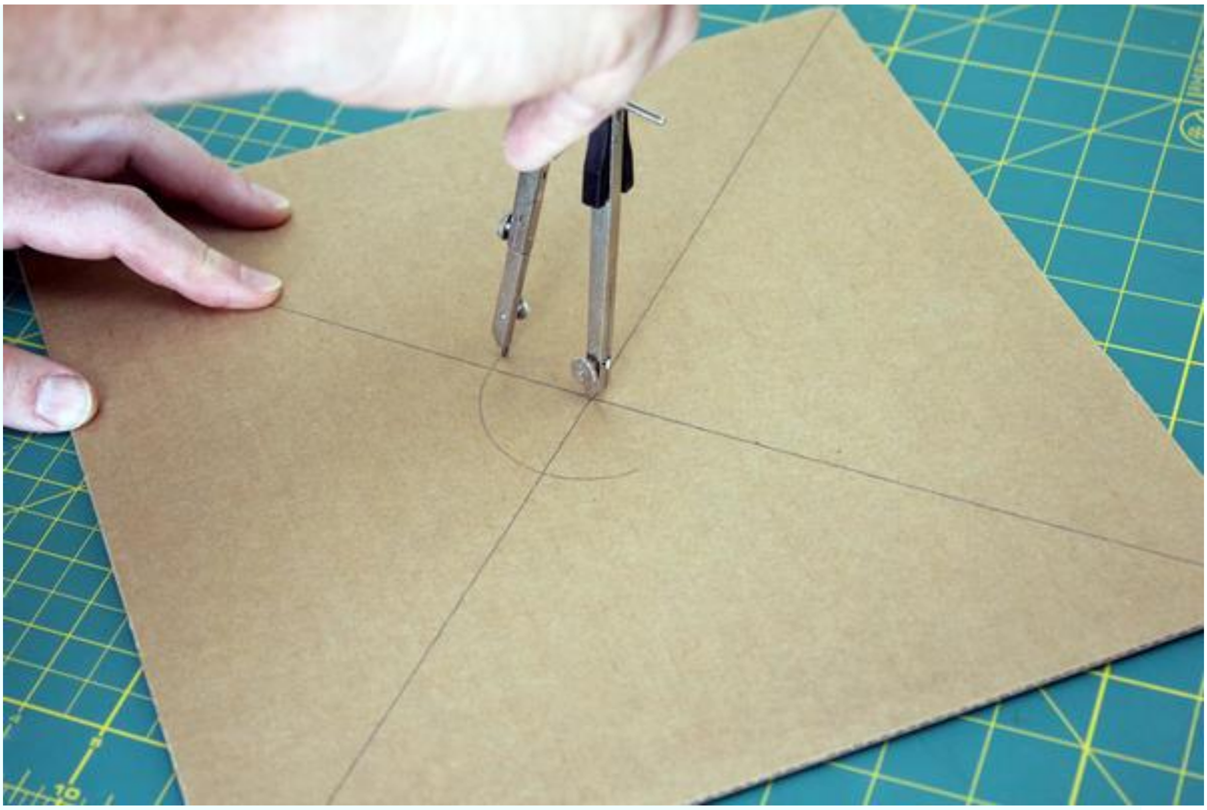


Figure 3-27. Draw guide lines from corner to corner across a 12” square sheet of corrugated cardboard, then draw a circle the size of the outside of the airframe centered where the lines cross.

Use a protractor to draw two lines spaced 120° from one of the guide lines. The guide line you picked and the two new lines are the centerlines for the three fins. Use a ruler and pencil to draw lines parallel to these guide lines that are 1/8” wide, which is the thickness of the fins. Mark the end of these lines 3” from the edge of the circle—this is the semi-span of the fin, and the amount it will stick out from the side of the rocket (see Figure 3-28).

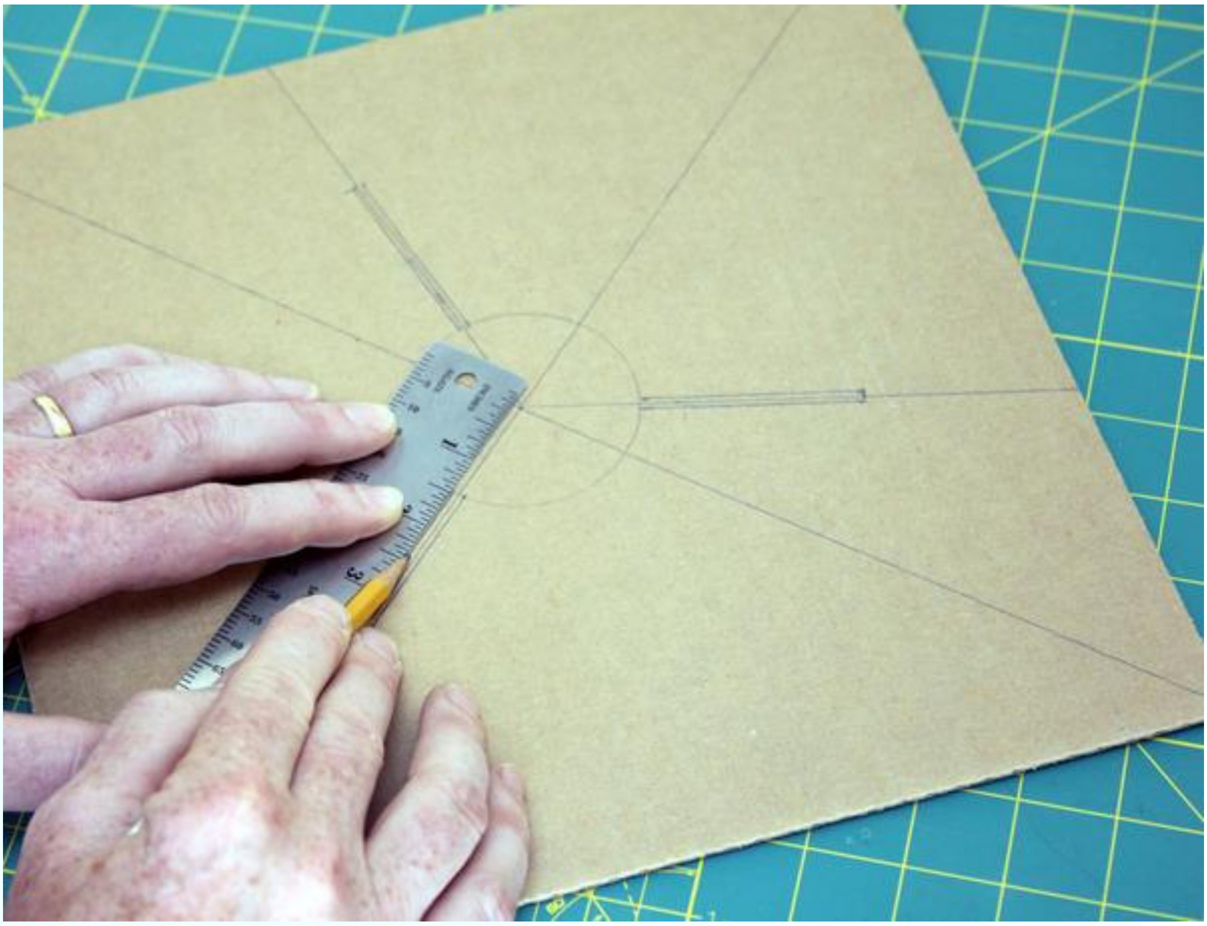


Figure 3-28. Draw lines for the sides of the fins 1/8" apart, centered on the fin guide lines. Mark the end of the fins 3" from the side of the airframe.

Use a hobby knife to cut out the hole for the airframe and the three slots for the fins.

CUTTING THE FIN SLOTS

Cutting the fin slots is one of the most harrowing parts of building a rocket. The slots must be absolutely parallel to the direction of flight. If they are off, the rocket could spin out of control. It could even spin fast enough to rip apart.

This causes some people to use jigs to cut the lines perfectly. You can find instructions for building a wide variety of home-built jigs by looking around online, and there are a couple of expensive mechanical ones you can buy. If you are going to cut a lot of fins, or if you are sparing no expense to try and win a contest, go ahead and invest in a jig. It’s worth it. For the rest of us, though, it really isn’t necessary. Some care and a piece of right angle aluminum will do fine.

The main airframe for the rocket is made from a 2.56”-diameter, 30”-long LOC Precision body tube. You can use other kinds of tubes from other manufacturers, of course. If you change anything here, though, be sure to change it in the simulator, too, so you can see if the change affects the stability of the design.

Start by carefully marking the edges of the fins using your fin guide, as shown in Figure 3-29. Mark two other guide lines halfway between two fins, too. You will use these two extra lines for the launch lugs and rail buttons.

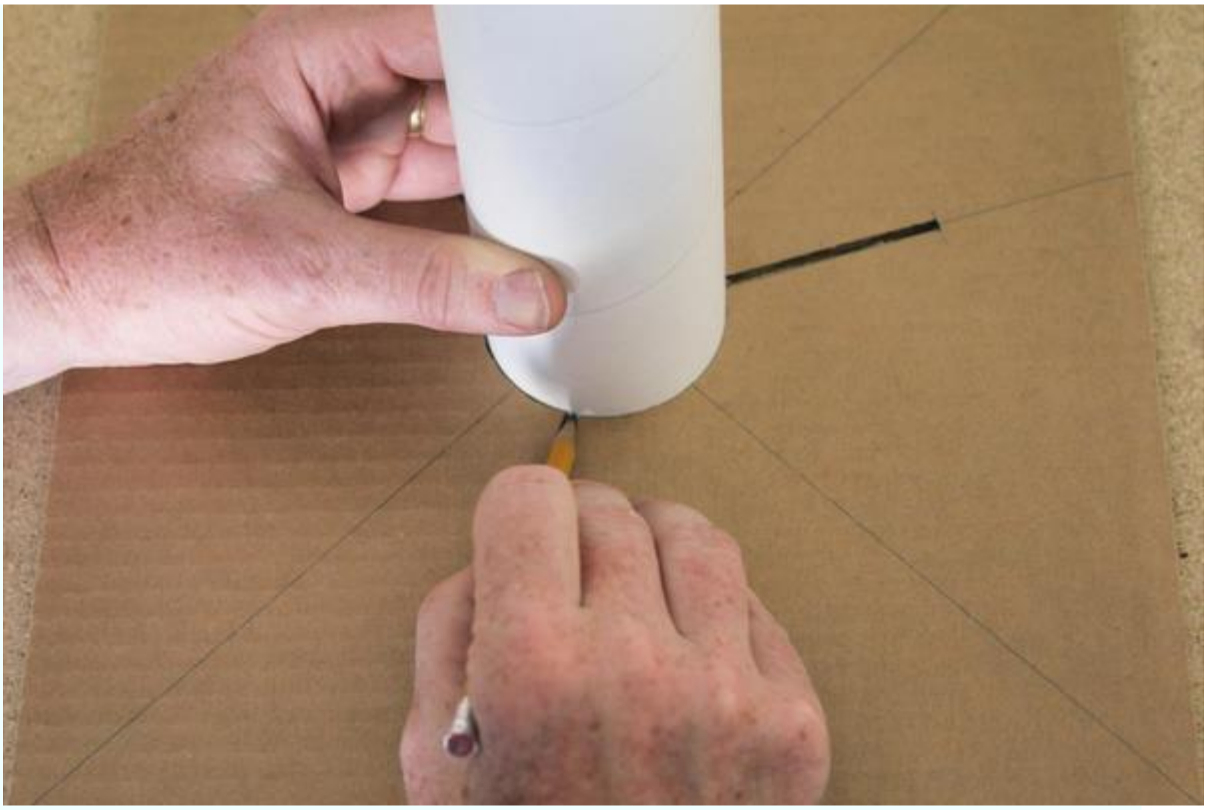


Figure 3-29. Mark the edges of the fins and two lines between two different fins using your fin template.

You need to draw very straight lines from the pencil marks to mark the locations of the fin slots and the lines the rail buttons and launch lugs will be on. If you started in low-power rocketry, you are probably accustomed to using a door jamb or the edge of a drawer to draw lines along a body tube. High-power rockets are too long and too thick for that to work well. Instead, invest in a piece of 90° aluminum stock, which you can get at almost any hardware store. Lay this along the body tube, and it will settle into a position parallel to the tube. Use the edge of the aluminum to draw lines from the bottom of the tube to about 6” up for the edges of each fin slot. Draw the lines for the launch lugs and rail buttons along the entire length of the body tube (see Figure 3-30).

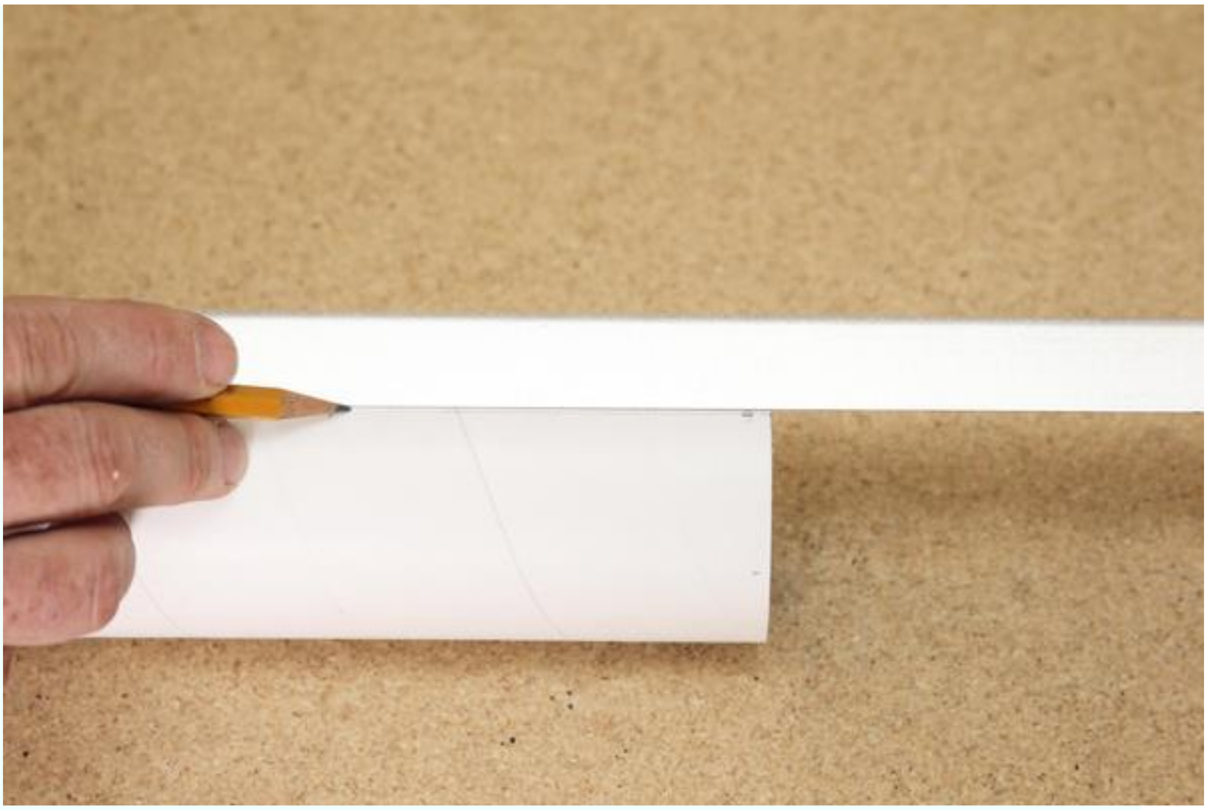


Figure 3-30. Use a piece of 90° aluminum to draw lines perfectly parallel to the body tube. Draw lines about 6” long for the edges of the fins, and along the entire body tube for the rail buttons and launch lugs.

Once the lines parallel to the airframe are drawn, draw the top and bottom of each fin slot. The bottom of the fin slot should be 1/2” from the bottom of the body tube, while the top of the fin slot is 5 3/16” from the bottom of the body tube, or 4 11/16” from the bottom of the fin slot.

Use the 90° aluminum as a guide when cutting the fins (see Figure 3-31). The body tube is thick paper, which is very easy to cut with a hobby knife. Make several shallow cuts rather than one deep one, working slowly and carefully to cut the fin slots parallel to the airframe.

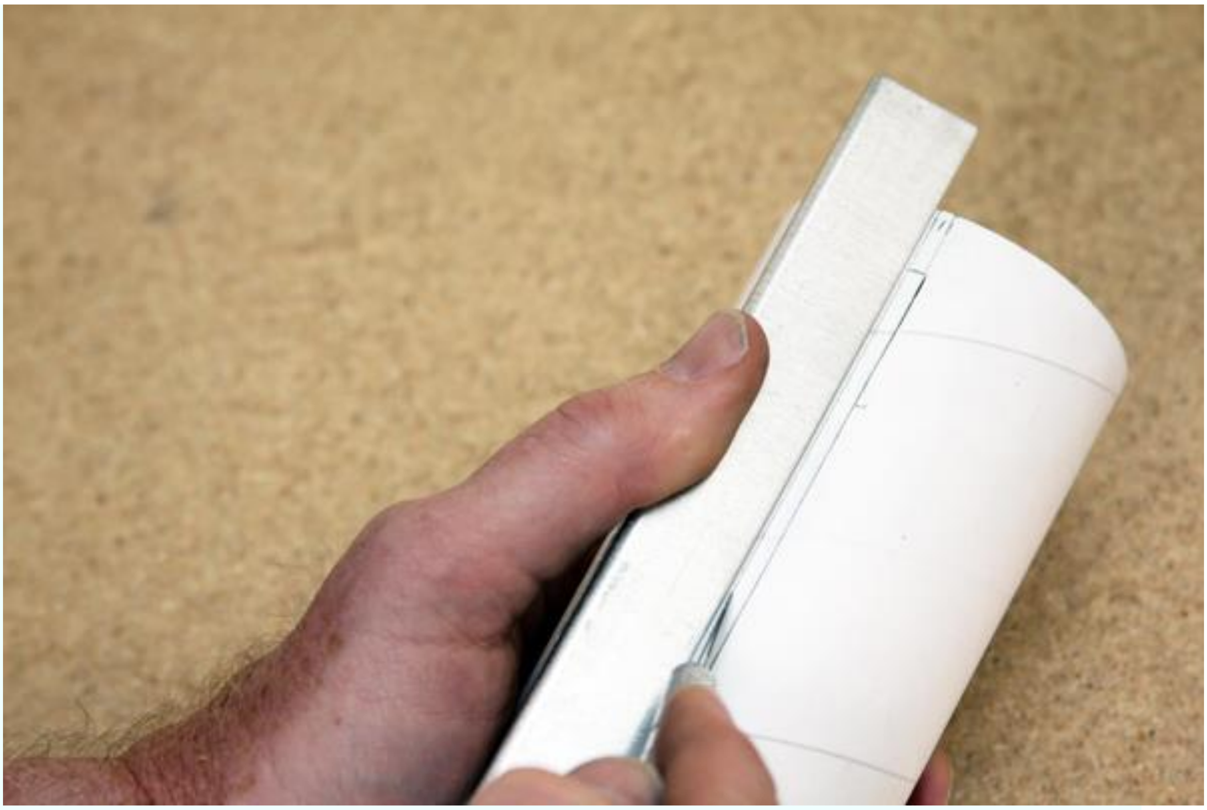


Figure 3-31. Use the 90° aluminum as a guide to cut the fin slots.

As you cut each fin slot, test the slot with one of the fins (see Figure 3-32). They are all the same size, so you only need to test one fin in each slot. (They *are* all the same size, right?)

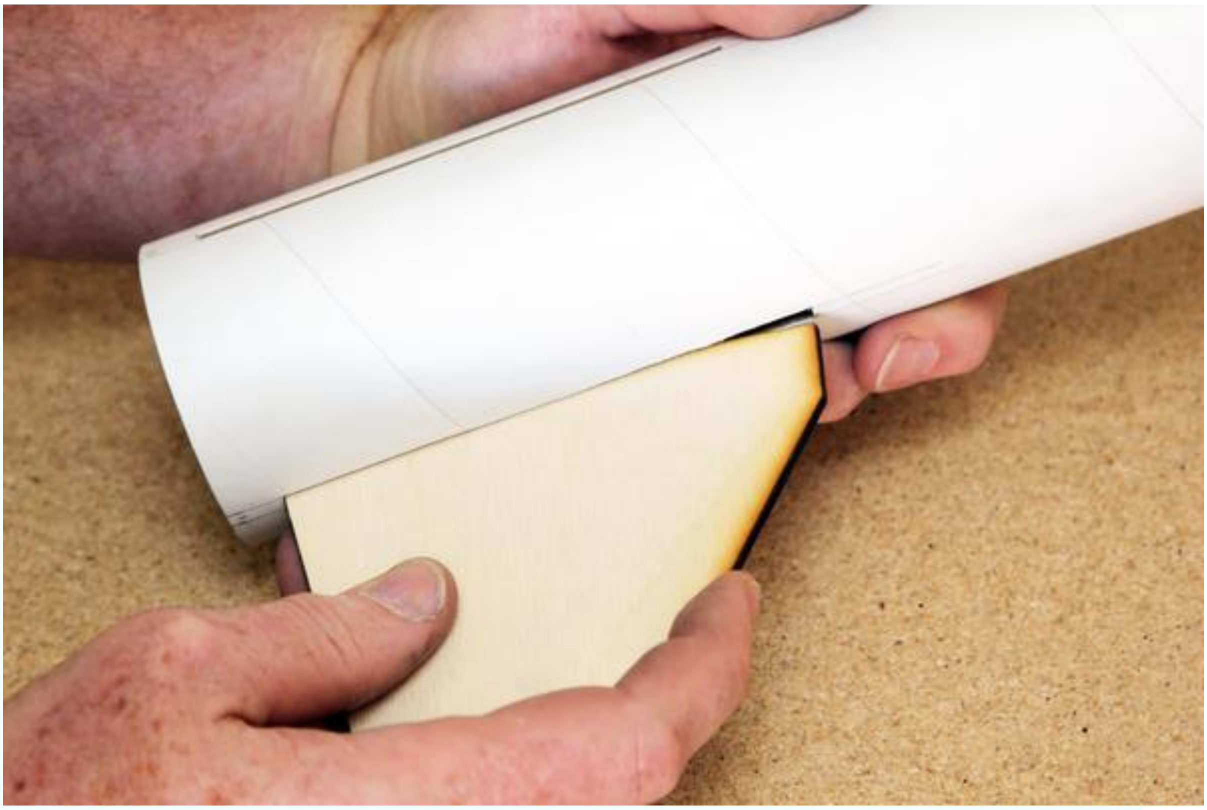


Figure 3-32. Test a fin in each fin slot as you go.

Don’t panic if you mess up a bit, as long as you can get the fin in straight. It’s definitely easier to get the fins glued in properly if the fin slots are perfect, but there will be enough epoxy around the joint between the fin and the body tube to cover up small mistakes.

If you’re not quite ready to tackle cutting your own fin slots, there is an alternative. LOC Precision sells an airframe with precut fin slots. It costs about twice as much as an airframe with no fin slots, but the slots are cut with absolute perfection by a laser cutter. The slots are 4 11/16” long. Coincidence? I think not!

Figure 3-33 shows LOC Precision airframe tubes with and without the precut fin slots. Look around if you are buying an airframe from a different source. Several other manufacturers also offer precut fin slots, and some will even cut custom fin slots.

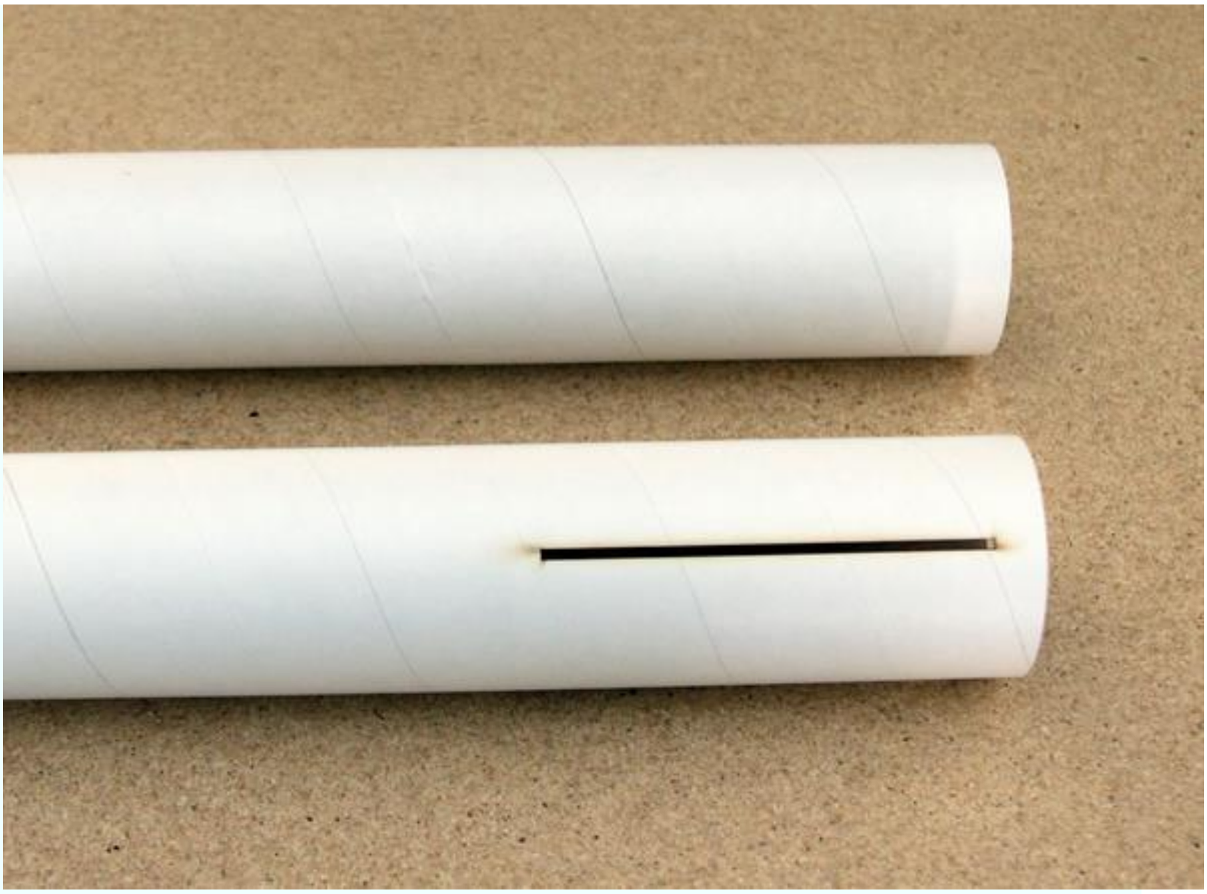


Figure 3-33. LOC Precision and some other manufacturers offer body tubes with precut fin slots.

Cutting the Payload Tube and Motor Mount Tube

The payload bay is made with a 10” section of airframe tube. The tube is already cut if you bought the payload kit from LOC Precision, but you will need to cut a 10” piece from a longer tube if you bought two full-length airframe tubes.

The motor mount tube has an inside diameter of 29 mm and is 8” long. LOC Precision sells these tubes in 34” lengths, so this tube definitely needs to be cut.

Either way, the process of cutting the tube is the same. We’ll look at how to cut the payload tube in detail. It’s a bigger tube, making the pictures easier to see. Follow the same process to cut the motor mount tube.

Mark the tube 10” from one end, and then wrap a strip of paper around the tube (see Figure 3-34). If you match the ends of the paper as you wrap it around the body tube, you are guaranteed a line that will give a perfectly perpendicular cut—assuming, of course, that you cut perfectly along the line!

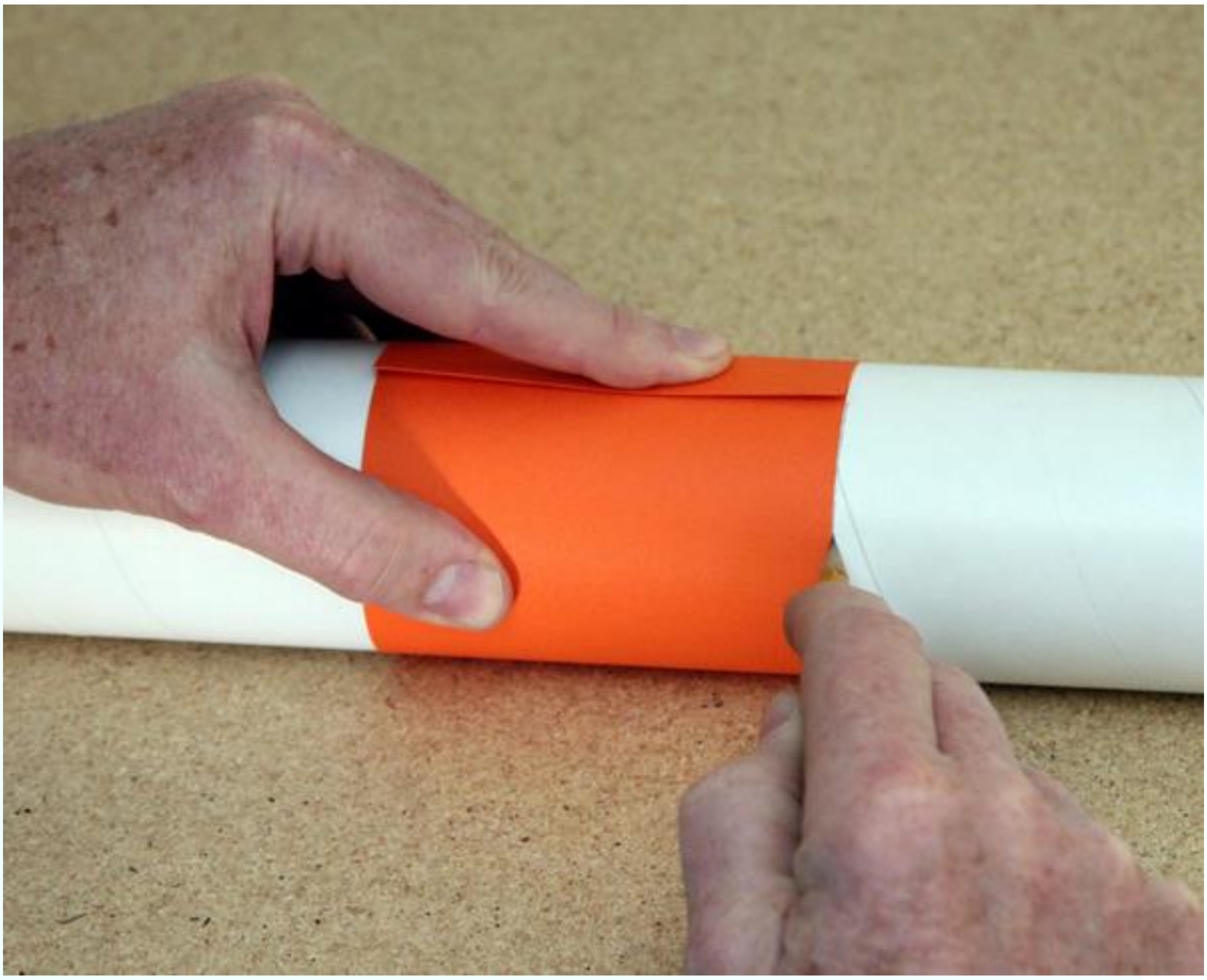


Figure 3-34. Mark the motor mount tube 8" from the end, then use a piece of paper to draw a circle around the tube.

You can cut the tube with a hobby knife or any fine-bladed saw. Make multiple shallow cuts if you use a hobby knife. If you use a saw, a good technique is to start the cut by sliding the body tube into the saw blade, but then finish the cut by rotating the tube into the blade. This gives a much better cut than sliding the tube all the way through the blade, as you would with a piece of lumber. It also allows you to cut some body tubes that would not fit through the saw. Figure 3-35 shows this technique.

The finished cut is not always perfect, either because the blade leaves small imperfections, or because we're just not as good as those perfect computer-controlled cutting machines. Whatever the reason, you can tidy up the cut with a belt sander, as shown in Figure 3-36, or by laying a piece of sandpaper flat on a table and carefully sanding in a circular motion until the end of the tube is perfect. It may sound odd to use sandpaper on a paper body tube, but trust me on this: it works. Paper is, after all, the original composite material. These thick paper tubes sand quite well.

Figure 3-35. Cut body tubes by starting the cut, then rolling the tube into the saw blade to cut around the guide line.

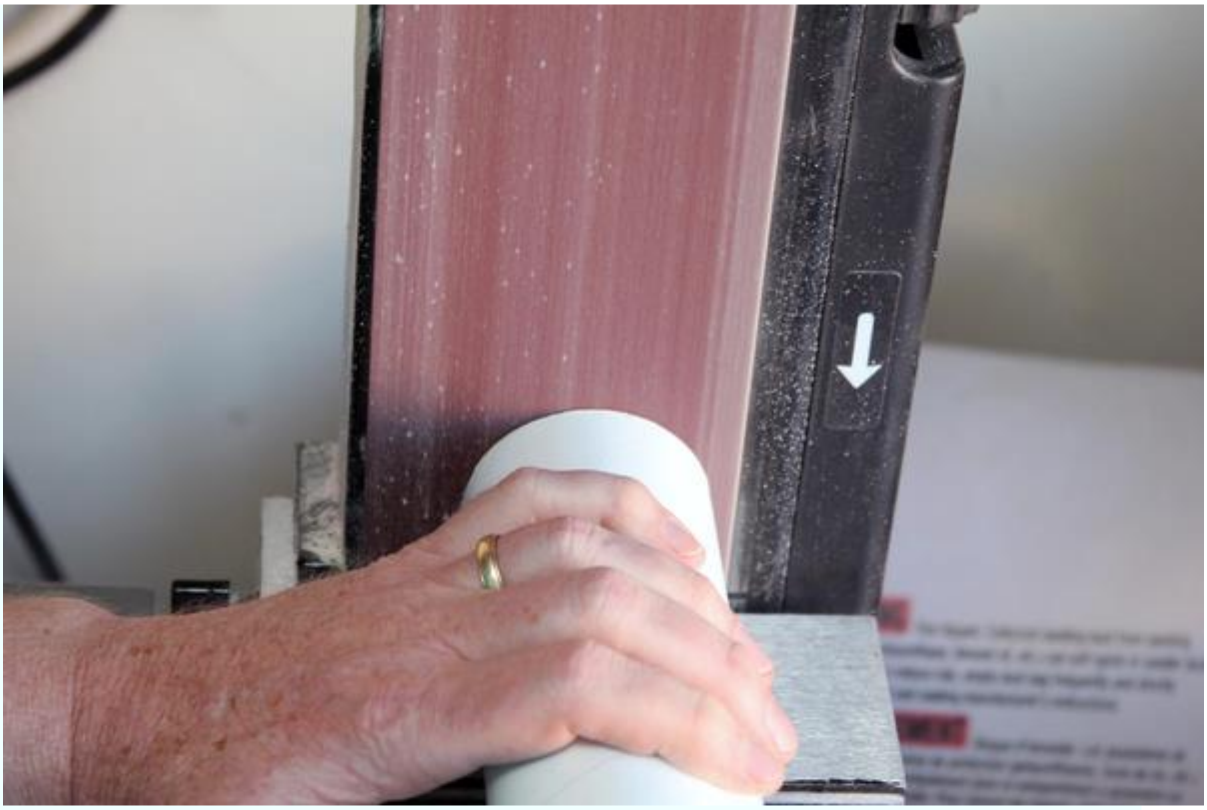


Figure 3-36. Clean up the end of the tube by sanding the end of the body tube with a belt sander or sandpaper on a table.

Installing the Motor Mount and Shock Cord

Pull out the parts for the motor mount and *dry fit* them to see how all of the parts fit together—and to make sure they actually do fit before you start applying glue! Dry fitting is just the term we use for putting parts together without the glue before actually using any glue.

The various parts you will need are the motor mount tube itself, the airframe with the fin slots cut, the three fins, the shock cord, and the motor retainer. All of these get glued in using a carefully orchestrated process that results in a solidly built rocket that won't fall apart in flight. Be sure to read the instructions carefully, dry fitting the parts as you go, to be sure you understand how the process will work *before* you start applying glue. Once you start applying glue, you have to move quickly through the various steps of the process. You won't have time to stop and reread these instructions.

The two centering rings will eventually be glued to the front and back of the motor mount, about 1/2” from each end. It is normal for them to be too tight in the airframe tube or too tight to fit over the motor mount tube. Lightly sand them until they fit easily, but don’t sand them so much that they allow the tubes to wobble.

The shock cord will slip through the forward centering ring and be glued around the motor mount tube. Cut a small notch on the inside ring of one centering ring. It should be just large enough for the shock cord to slip through.

Mix a small amount of 5-minute epoxy, about a tablespoon total. Working quickly, glue the forward centering ring 1/2” from the end of the motor mount with about 4” of the shock cord pulled through the slot. Wrap the 4” length of shock cord around the motor mount tube, applying epoxy under and across the top of the shock cord to glue it firmly to the motor mount tube (see Figure 3-37).

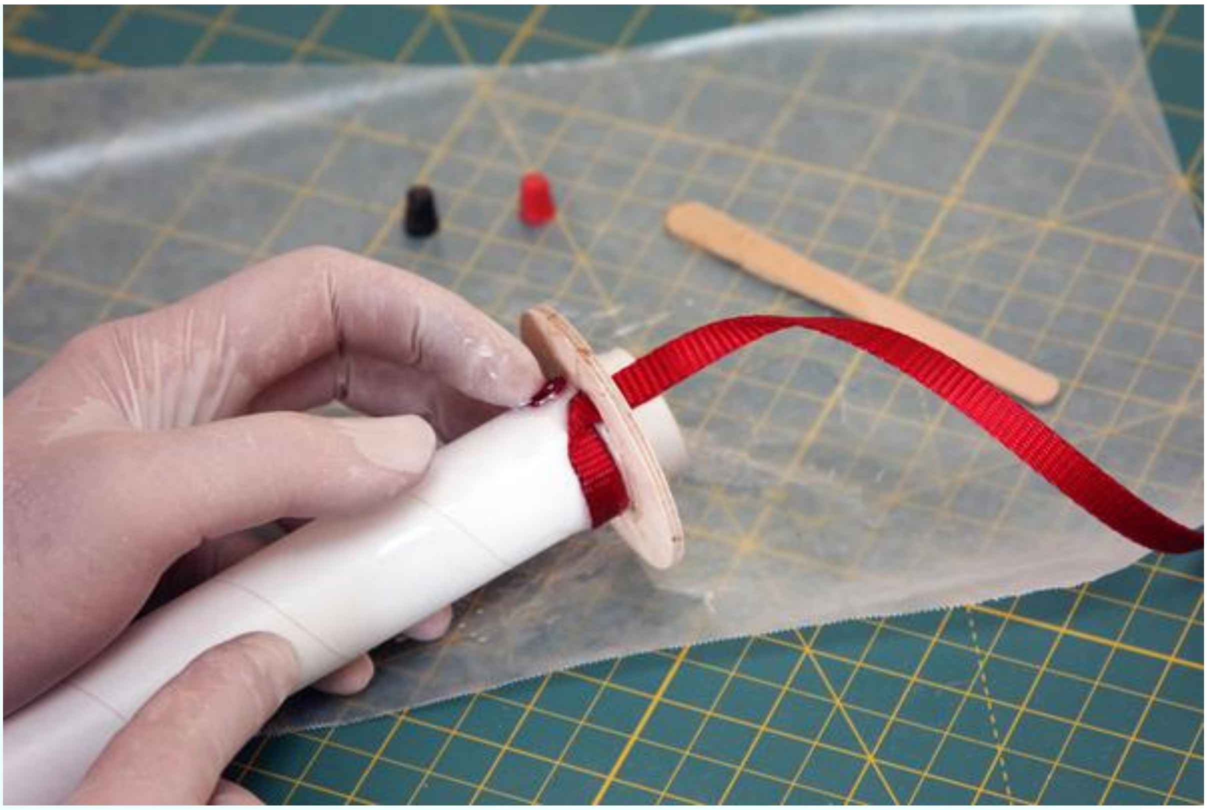


Figure 3-37. Poke the shock cord under the forward centering ring and wrap it around the motor mount tube. Glue both the centering ring and shock cord in place.

Wrap some tape around the shock cord to hold it in place while the glue dries (see Figure 3-38). The tape is only used to keep things in place while the glue is drying, but you can leave it in place afterward. It won't be visible on the finished rocket.

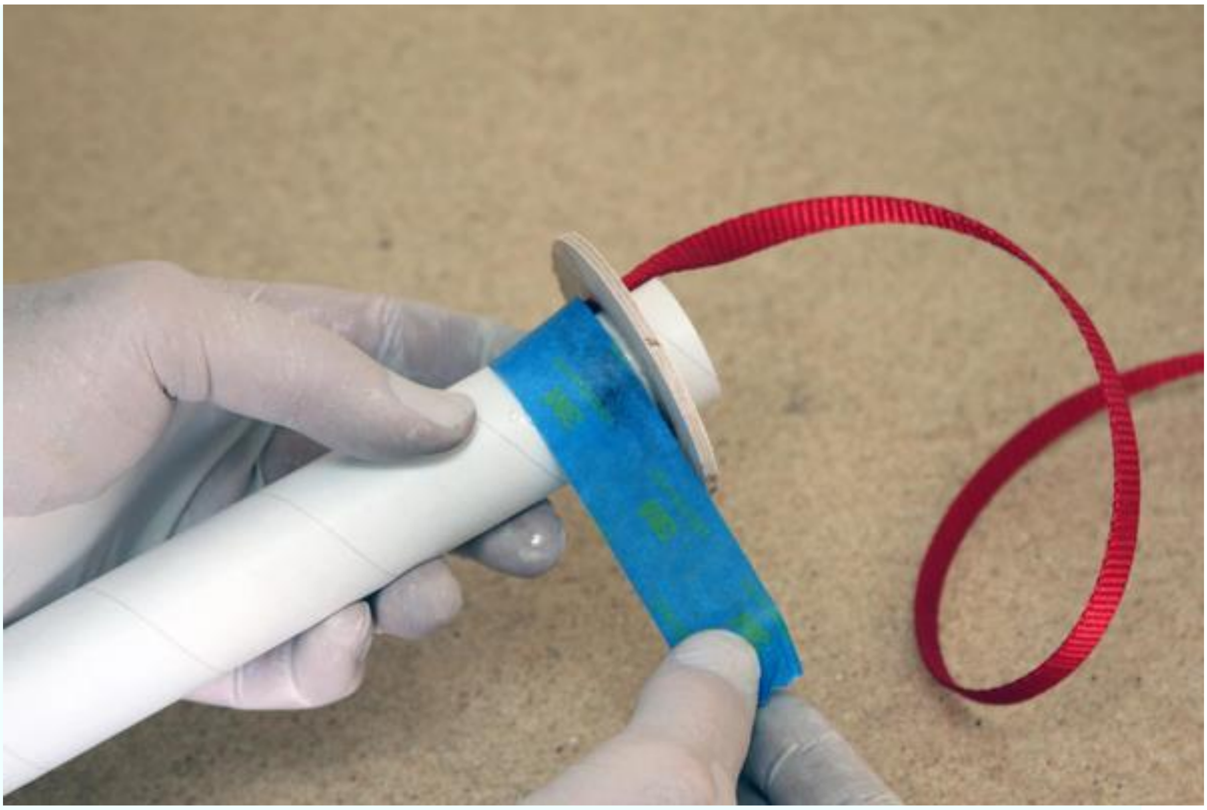


Figure 3-38. Wrap tape around the shock cord to hold it in place while the glue dries.

Pushing the centering ring into the ring of epoxy on the motor mount tube forming a nice fillet on the lower edge. Once the glue gels well enough that it won't run, which should take about 10 minutes, use a popsicle stick or scrap of wood to create a thick fillet of glue on the other side of the centering ring, too.

You will want to let this piece dry completely before moving on to the next step, but that doesn't mean you have to stop working on the rocket entirely. These instructions are presented in a logical order so the steps are clear. You can easily skip ahead and start working on the payload section while the glue dries on this part.

Dry fit the parts once again. This time you will be gluing the forward centering ring in place. You will slide the aft centering ring into place, but don’t glue it! In fact, wrap some dental floss around the centering ring so you can pull it back out later, as shown in Figure 3-39. The shock cord will be dangling near glue during this operation, so tape most of it together to make it less likely you’ll need to clean up any glue. Leave enough loose so the shock cord fits all the way through the tube.

You Can Also Use Wood Glue

Epoxy is a great glue for all high-power rockets, but there is another glue that is just as good for fastening paper and wood. Like epoxy, wood glue is stronger than the paper or wood. One of them, usually the body tube, will tear or break before the glue gives way.

One caution with using wood glue is that it takes a really long time to dry, if it ever dries at all, when it is used in enclosed spaces. Keep that in mind before you glue the second centering ring in place. Make sure the glue has dried for at least a day before closing off all of the fin fillets with that second centering ring.

Also, remove the tape in this step once the glue sets. This will help the glue holding the shock cord in place to dry completely before the second centering ring is glued into place.

Wood glue can soften in very humid or wet conditions. That’s not a particular worry here in New Mexico, but I remember paper feeling different in muggy Indiana summers. Epoxy is a better choice in humid environments.

Other than letting the glue in enclosed spaces dry very thoroughly, building Callisto with wood glue follows the same process as gluing it with epoxy.

Using wood glue also avoids the hazards of allergic reactions with repeated exposure to the glue.

Cyanoacrylate (CA) glue, also called super glue, can be used, but it is rare in high-power rocketry. If you do choose CA glue, be sure not to use it near elastic or rubber parts, since it can react with those parts and weaken them.

Apply a very generous amount of 5-minute epoxy about 7” inside the main airframe using a long stick (see Figure 3-40). Form a complete ring, and use plenty of glue. Two popsicle sticks taped together work well for this purpose, but any piece of scrap wood that is long enough will do.

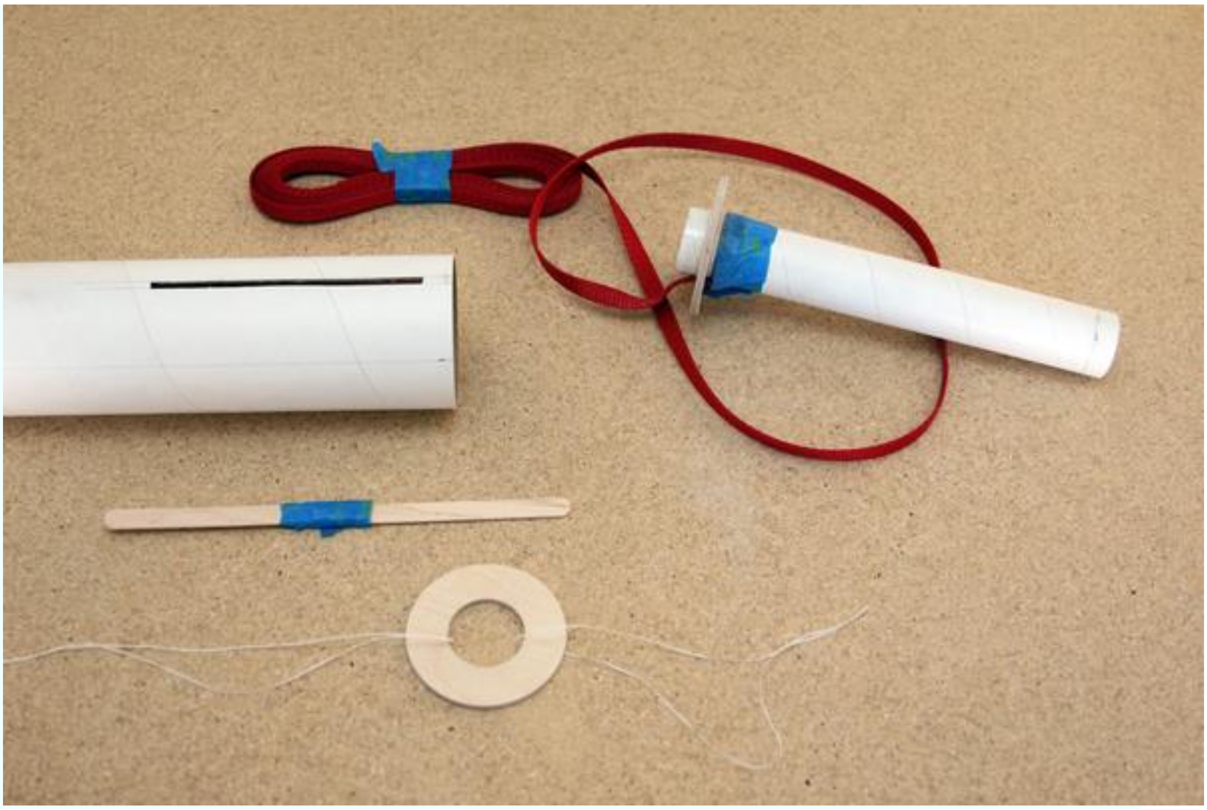


Figure 3-39. You will need the motor mount assembly from the last step, the aft centering ring with dental floss for a handle, the airframe tube, and a long stick for the next step.

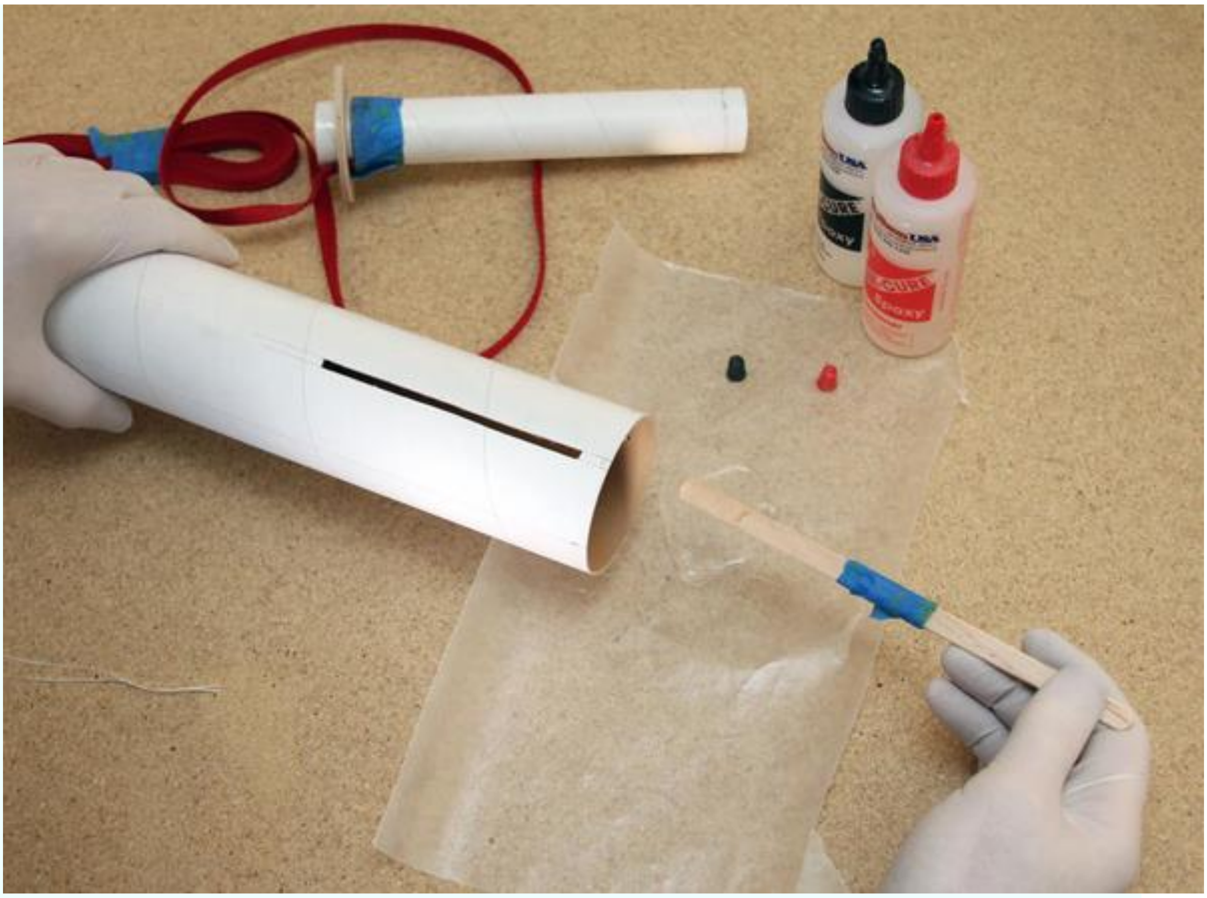


Figure 3-40. Apply a thick ring of glue 7” inside the main airframe.

Slide the motor mount into the airframe. The forward centering ring will slide through the glue ring, pushing it forward in the body tube. This coats the joint between the centering ring and the body tube with glue. The glue that is pushed forward will form a fillet on the forward side of the centering ring. The aft centering ring is put in place to make sure the motor mount tube is centered, but do not glue it in place or let any glue touch it.

You need to be careful during this step, because the shock cord will drop through a ring of epoxy, and you don’t want to get any glue on the shock cord. You can manage this by holding the tube vertical while you drop the shock cord through, and then rotating it down so the side with the shock cord is on top. If you do get any glue on the shock cord, clean it off right away with rubbing alcohol. Rubbing alcohol cleans up epoxy nicely while it is wet.

The end of the motor mount tube should be even with the end of the airframe (Figure 3-41).

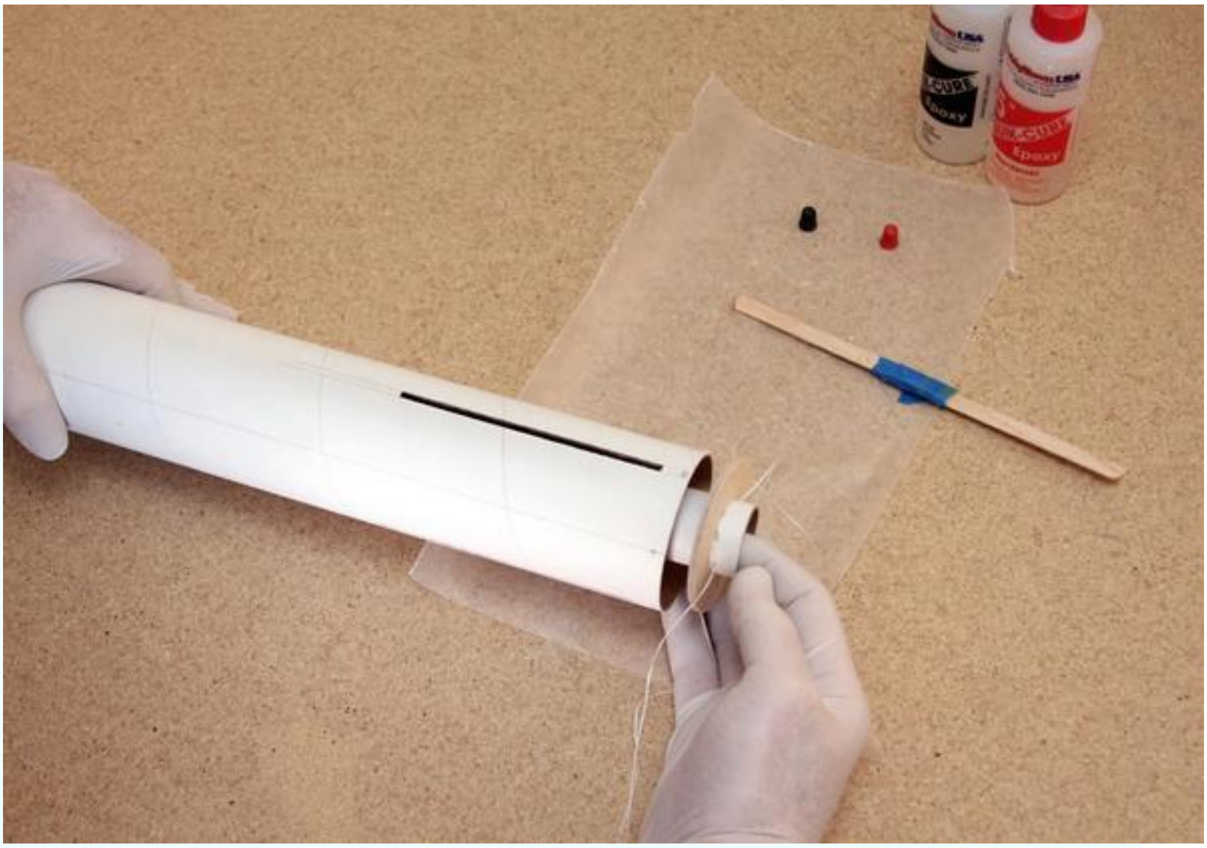


Figure 3-41. Slide the motor mount into place.

Stand the rocket up on its end and let these parts dry thoroughly (see Figure 3-42). The epoxy should still be thin enough to flow around the joint on the top side of the centering ring, securely fastening the parts together. You can check this with a flashlight, turning the tube to allow the glue to run around the outer edge to make a good joint.

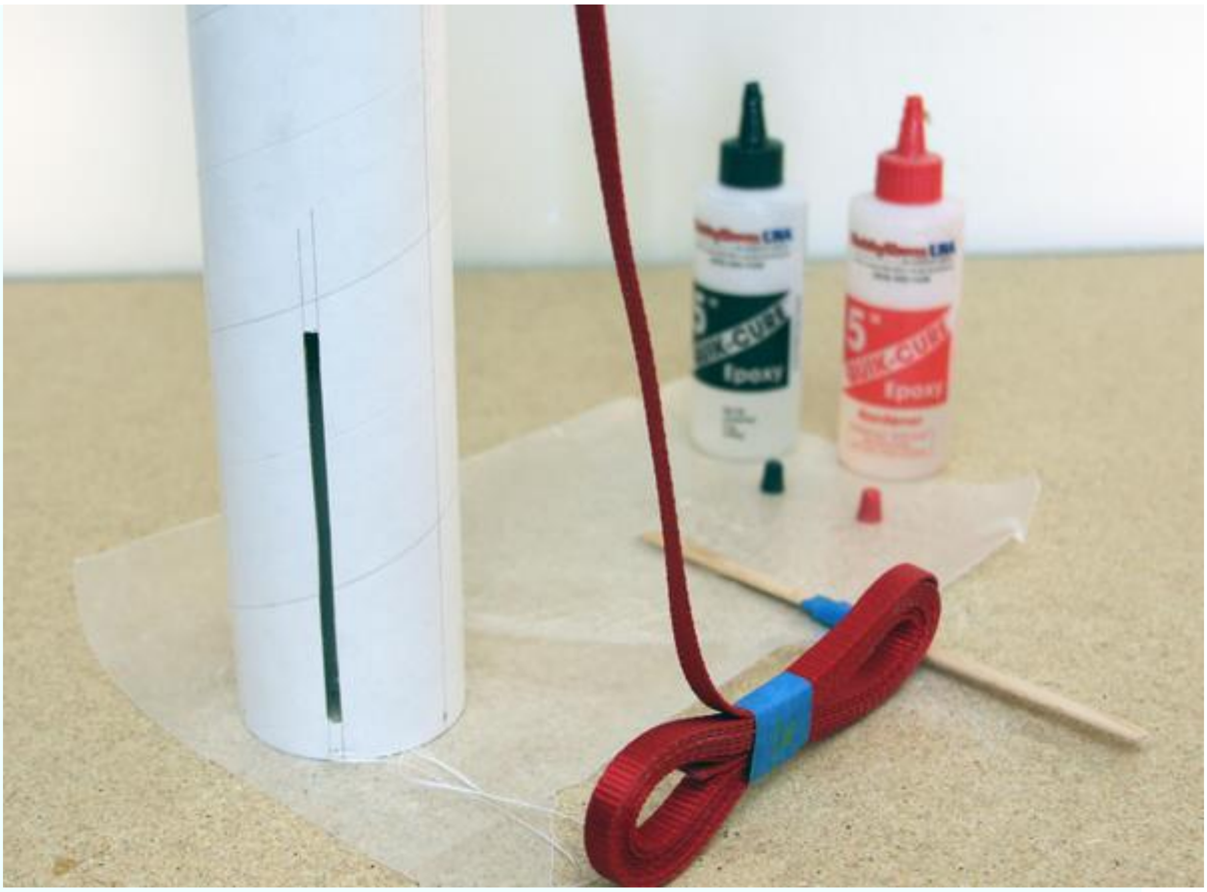


Figure 3-42. Stand the rocket on its end and let the parts dry. Wait until the parts are firmly dry before proceeding.

Installing the Fins

Once the glue has dried completely, pull on the dental floss to remove the aft centering ring. Apply 5-minute epoxy to the root edge of each fin and push them into place. Slide the fin template over the fins and airframe to hold them perfectly straight while the glue dries. The fin slots will hold the fins parallel to the airframe. The fin template will hold them perfectly angled perpendicular to the airframe (see Figure 3-43).

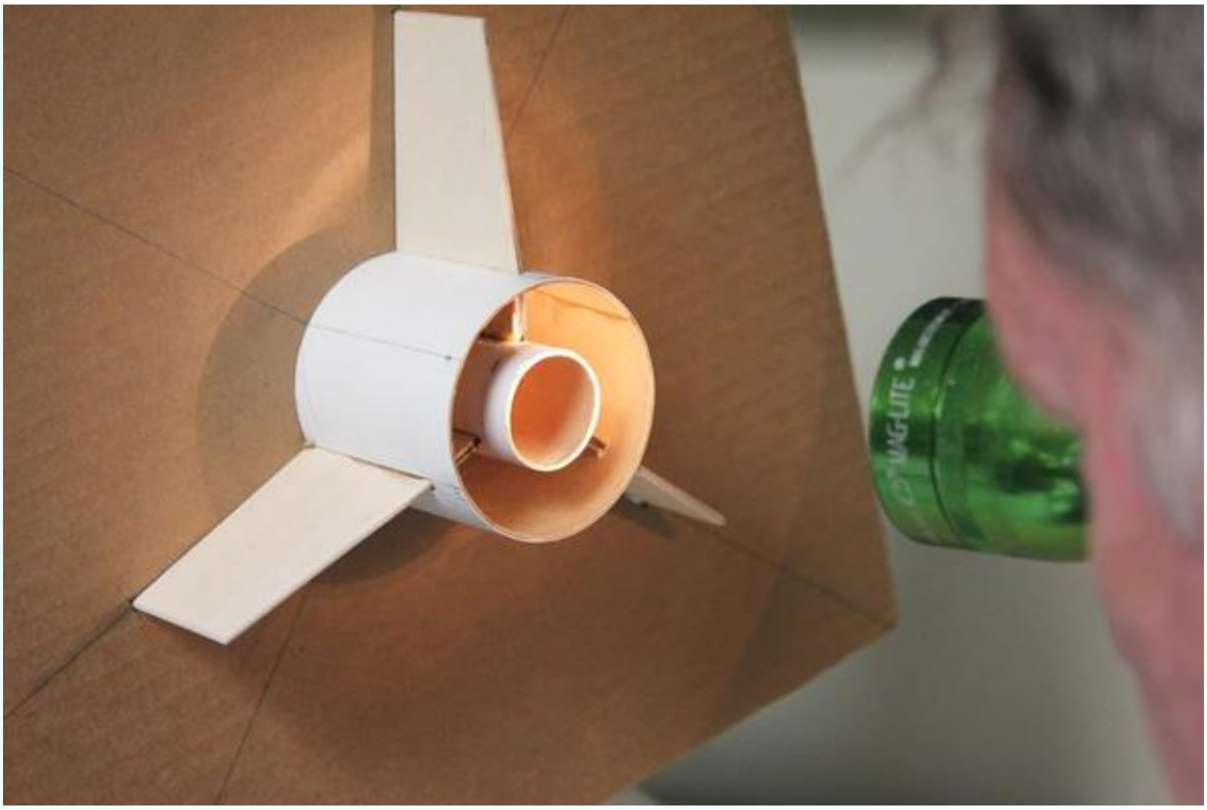


Figure 3-43. Glue the fins in place, using the fin template to hold them straight.

You need enough glue to tack the fins in place, but there is no need to get carried away by applying tons of glue. We'll do that later.

Check the fins with a flashlight as soon as they are in place. Check them again every minute or two for at least 10 minutes to make sure none pull away from the motor mount tube. All three fins must be firmly attached to the motor mount tube. At this point, the issue is alignment, not strength—we're going to use glue fillets to add strength in a moment. This step is about tacking the fins firmly in place so they don't move during the rest of the process.

Once the glue starts to set, but before it is completely dry, check the alignment and position of the fins one last time. It's still possible to pull a fin off and reposition it if there is something wrong. If you need to do that, scrape the soft glue away using a hobby knife or wipe away the glue using a paper towel soaked in rubbing alcohol. The rubbing alcohol works well while the epoxy is in liquid or gel form; the hobby knife works well from the time it starts to harden until it cures. Once it cures, it's pretty tough to dislodge, though.

You don’t have to wait for the epoxy to cure completely before moving on to the next step, as long as you make sure the epoxy is firmly set. A good way to check that is to leave the popsicle stick you use to mix glue in the puddle of excess glue on the wax paper—assuming you use popsicle sticks and wax paper like I do. The glue is hard enough to move to the next step when you can peel the popsicle stick up and the remaining glue comes off as a fairly rigid plate. You can probably still bend the glue, and that’s fine, as long as it holds its shape well.

The next step is to apply very generous epoxy glue fillets to all of the locations where a fin meets a tube. We’ll do this in three steps. Figure 3-44 is an end view of the rocket that shows the plan. The red and green colored areas are the epoxy fillets. Since the glue will run if it is applied to a vertical surface, orient your rocket so it is perfectly level with one fin pointing down, just like the drawing. You will then apply fillets in all of the red locations. Once these gel enough that the glue will not run, you will rotate the rocket 120° and apply another set of fillets. You will repeat the process to create the final six fillets.

So far we’ve used 5-minute epoxy for all of the tasks. That’s because the parts were fairly simple to assemble, and we didn’t need a lot of time to work with the glue. This next step is different. It will take a fair amount of time to work the glue into position and check to be sure it is even. Use 30-minute epoxy for all of the fin fillets. Make sure to keep a flashlight handy to check your work.

You will need to push glue around all the way to the back of the fins. Either fasten two popsicle sticks together or use a long stick, just as you did when applying the ring of glue to glue the motor mount in place. Get this ready before you start.

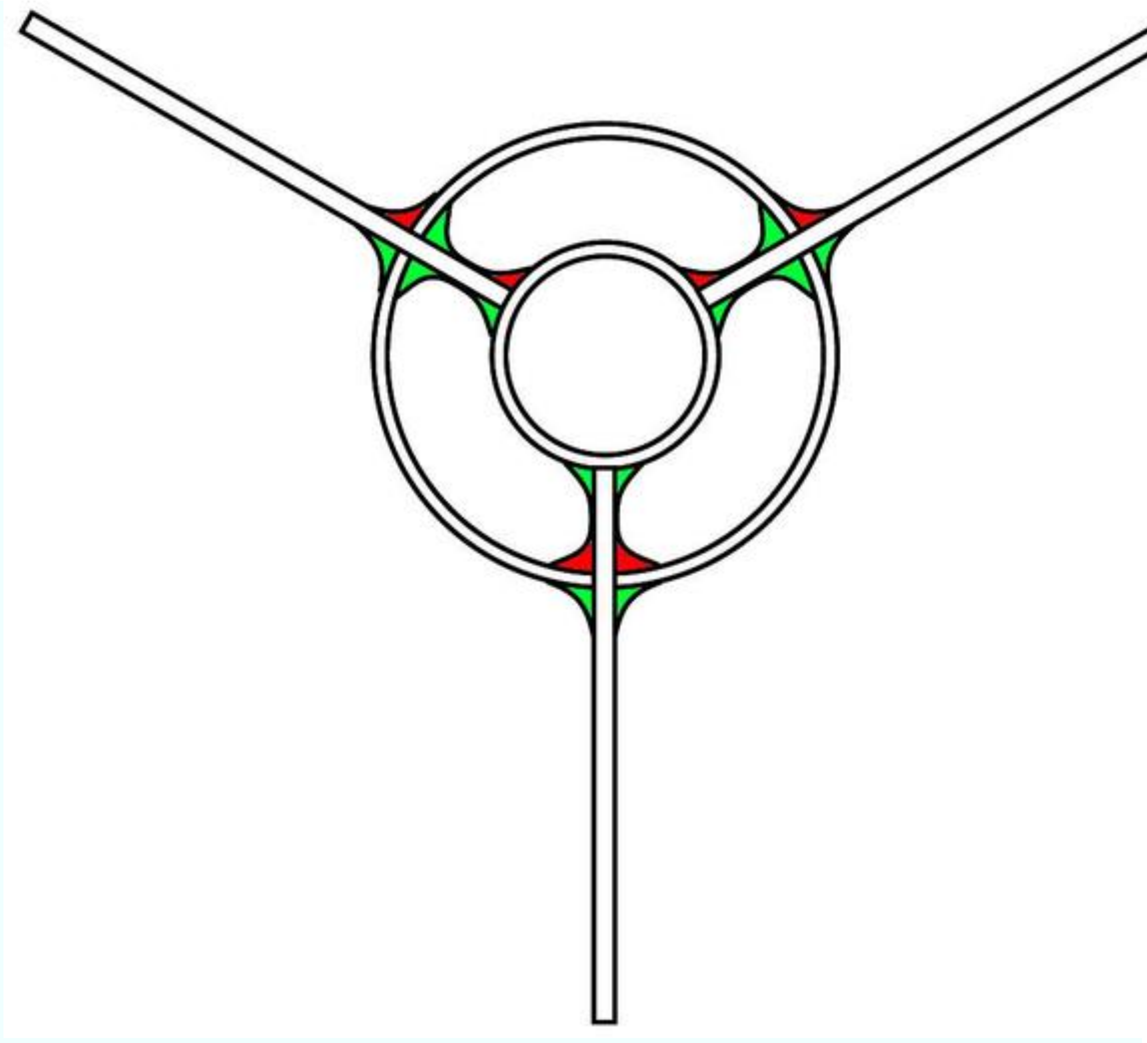


Figure 3-44. Apply fillets at all joints where a fin touches the airframe.

I also use a popsicle stick to form the fillets on the outside of the rocket.

You'll also need some paper towels and rubbing alcohol within arm's reach to clean up any epoxy drips.

Once everything is in place, mix a generous amount of 30-minute epoxy. You really can't use too much glue for the inside fillets. If it's not dripping off of the end of the fins, you're fine. Even if it starts dripping off the end of the fins, just wipe it up with a paper towel soaked with rubbing alcohol. It's really OK if the glue gets on the airframe tube or motor mount tube—just wipe away the excess. Any glue that soaks into the paper just makes it stronger! Use the long stick to push as much epoxy into the inside four fillets (the ones shown in red in Figure 3-44) as you can manage. Check these with the flashlight to make sure the glue gets all the way to the back of the fins. You can tip the rocket back and forth to work the glue forward and back, too (see Figure 3-45).

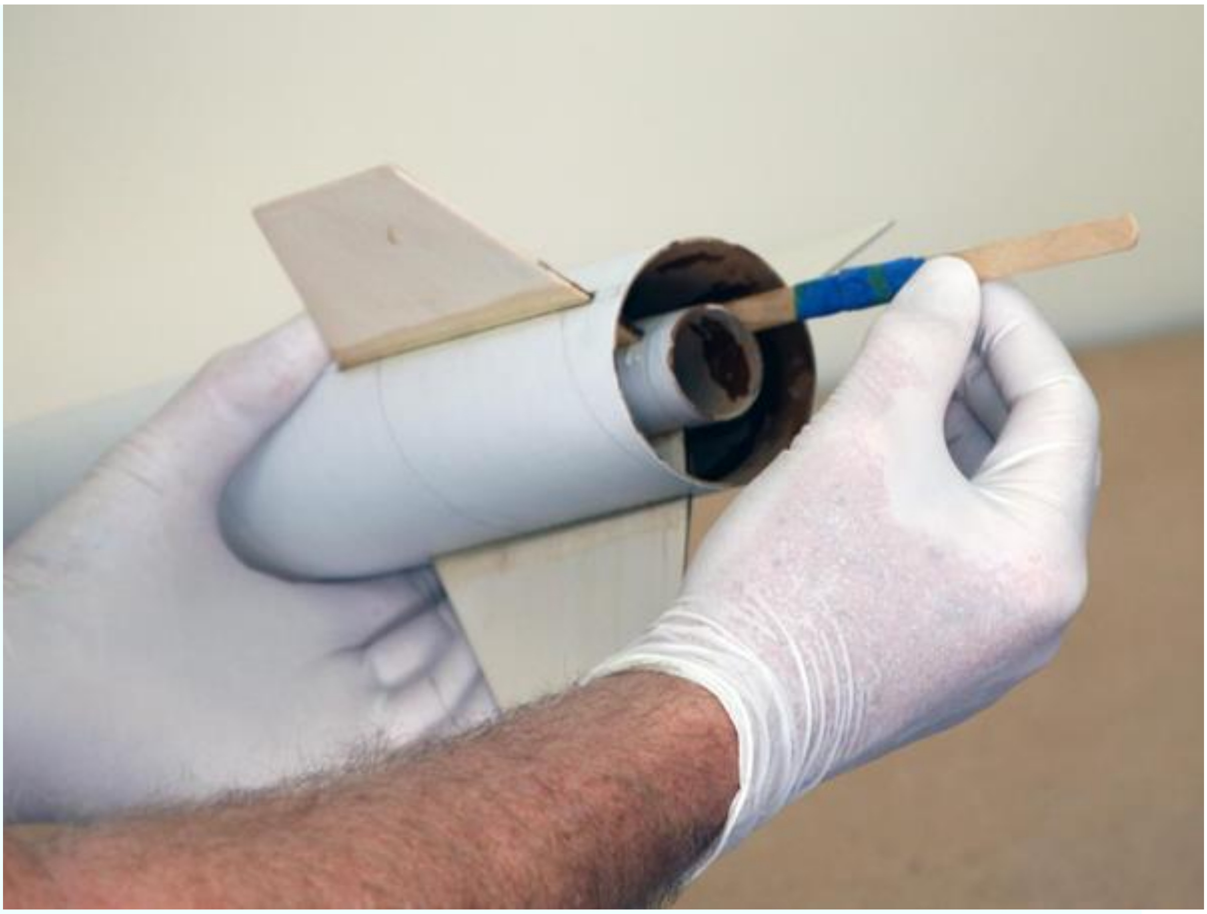


Figure 3-45. Work copious amounts of 30-minute epoxy into the interior fillet locations, tipping the rocket to help it flow into place.

Once the interior fillets are done, apply epoxy to the two fillets shown in red in Figure 3-44 on the outside of the rocket by dribbling it off of the end of a stick, then use a popsicle stick or other curved surface to form a nice even fin fillet. The inside fillets can be as messy as you like. The outside fillets will be in the airstream, though, so they need to be nice and smooth.

With a little experimenting, you will find you can control the thickness of the fillet by adjusting the angle of the popsicle stick. Hold it vertical for a thin fillet, or flatter, as shown in Figure 3-46, for a thicker fillet. You want a fairly thick fillet here. Oddly, a fillet even improves the aerodynamics a bit.

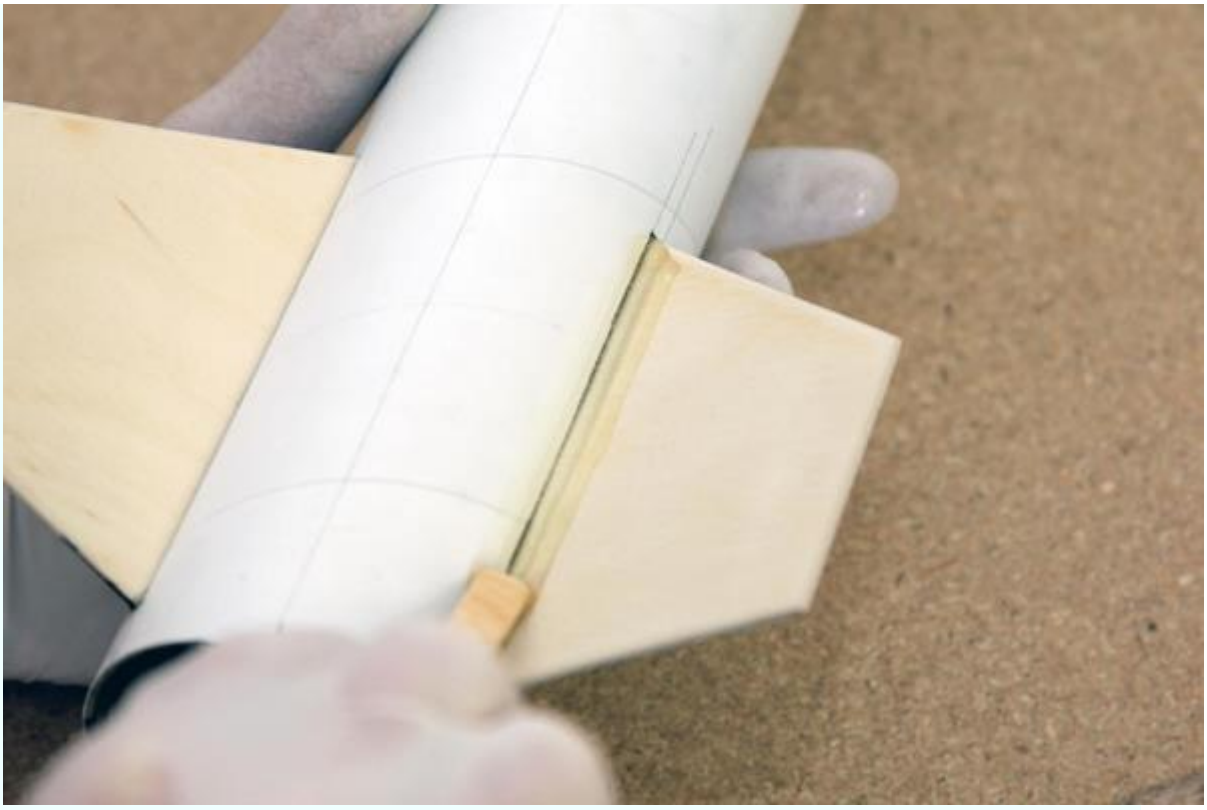


Figure 3-46. Use a popsicle stick or other curved surface to apply a smooth fillet to the two outside locations.

With all of the fillets in place, put the rocket in a spot where it is perfectly level while they set (see Figure 3-47). This will take about an hour from the time you mixed the epoxy, although the time can vary a bit due to temperature. The hotter it is, the faster the glue will set. Again, leave a popsicle stick in the puddle of leftover glue and test it periodically. You can move on to the next set of fillets once the glue is firm.

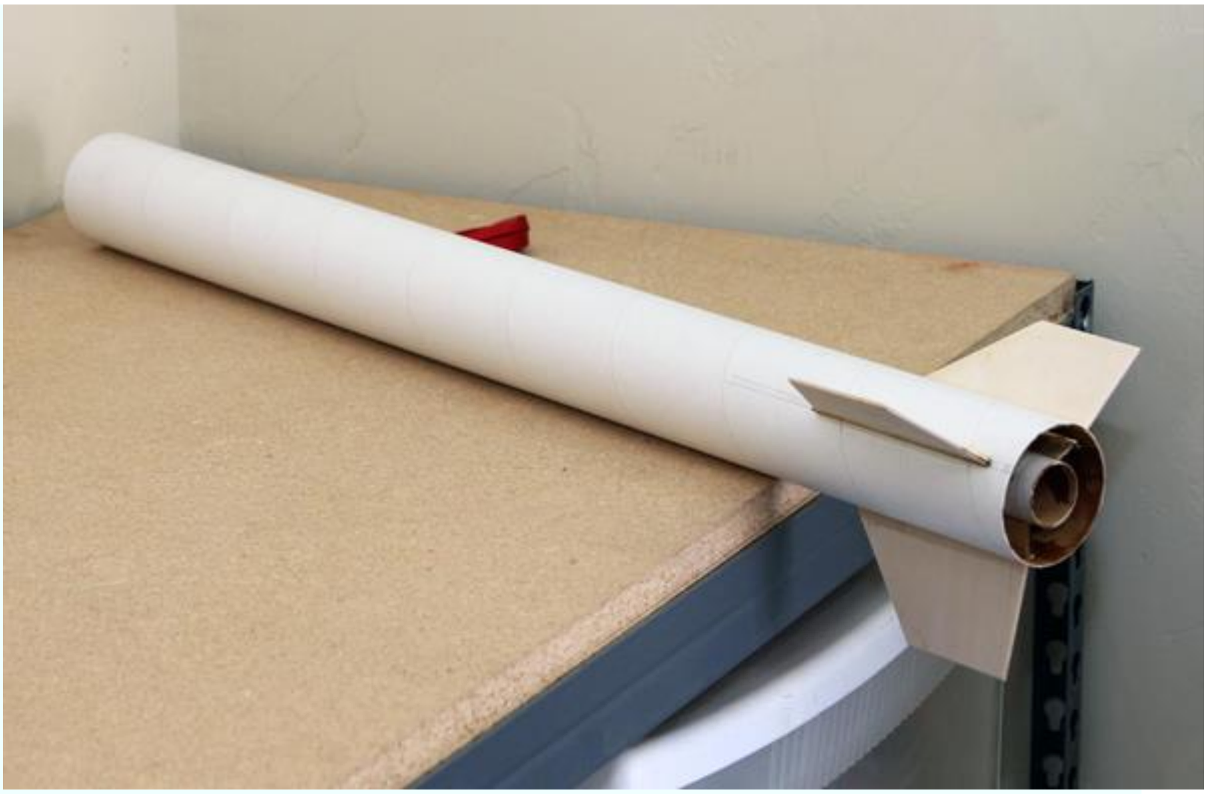


Figure 3-47. Place the rocket somewhere flat while the glue stiffens.

Check the fillets every 10 minutes or so. Clean up any drips with a paper towel soaked in rubbing alcohol, or with a hobby knife, depending on how dry the glue is at the time.

You can move to the next step, rotating the rocket 120 degrees and applying the next set of fillets, when the glue is fairly dry.

Adding Launch Lugs and Rail Buttons

Callisto has both launch lugs and rail buttons. It’s designed to be launched either from the 1/4” launch rods common on low- and mid-power launchers, or from launch rails that are more often seen on high-power launchers. Hopefully you have checked with your local rocket club by now, and know what to expect when you get to the launch site. If so, you may decide to leave one or the other off.

You will need two rail buttons. They usually come in a set of two, and include a plastic button and screw. The button is designed to slide into the slot formed by a common kind of aluminum rail called *80/20 rail*. The two common sizes used for rocket launchers are 1010 and 1515 rails; these are 1” square and 1 1/2” square, respectively. The smaller size is used for most high-power launchers. LOC Precision has rail buttons for these rails called Series 1000 rail buttons, and sells them in a package of two. Figure 3-48 shows a rail button sliding into the end of a launch rail.

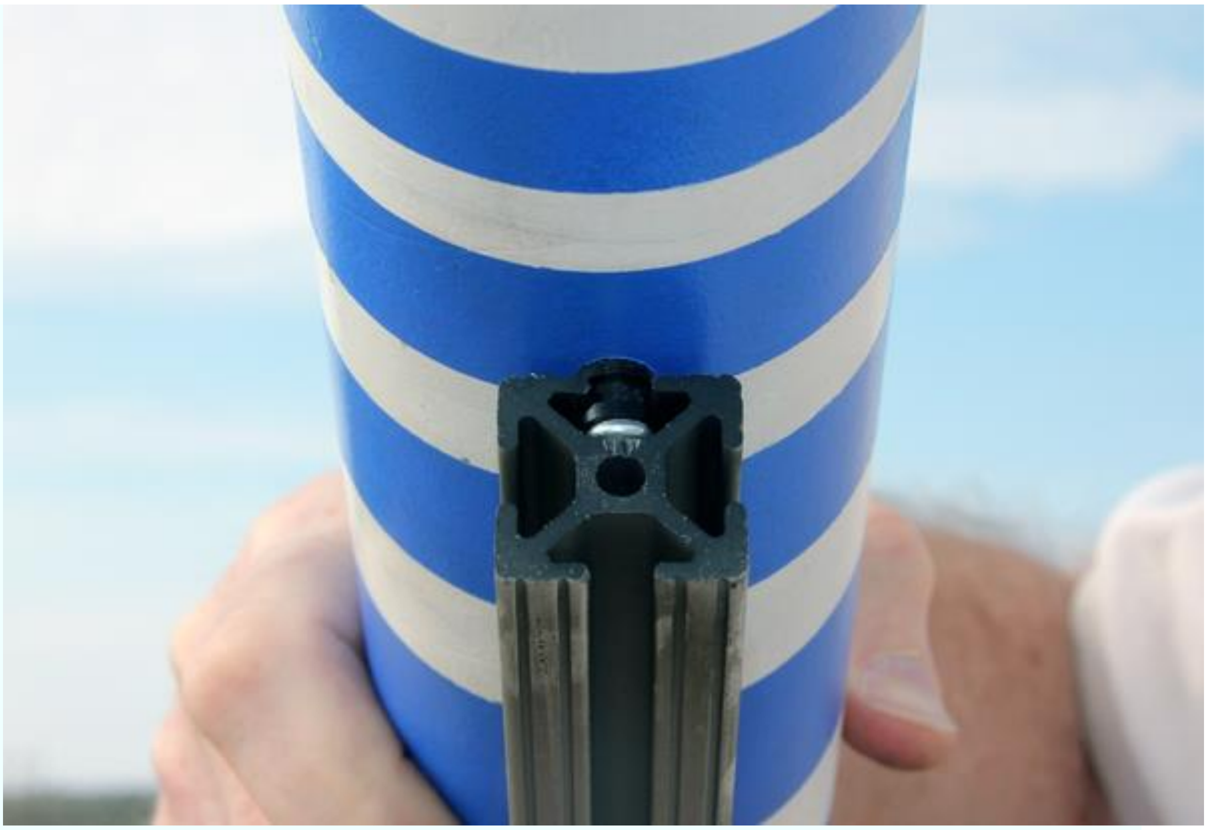


Figure 3-48. Rail buttons are designed to slide into the launch rail.

Callisto is small enough that you can get away with screwing the rail button into the paper, extracting it, applying a lot of epoxy, and then reinserting the screw. We're going to use a nut, though. It's possible to use a standard 8-32 nut that you can pick up at any hardware store with a LOC Precision rail button, but you get more strength (and installation is easier) if you use a large rectangular nut like the ones shown in Figure 3-49. The commercial nut is designed for use on 1010 rails, where it slides into the rail itself so a part can be bolted to the rail. The homemade nut was made by… well, let's have a look. It's a good skill to have for making all sorts of rocket parts.

The homemade rail button nut is made from a piece of 3/4" x 1/8" aluminum bar, something you can get at almost any hardware store or from online retailers like Amazon. Brass and steel are good options, too, though steel is harder to work with. You will also need a tap and die set for tapping an 8-32 hole. It will come with a drill bit that is the perfect size for your hole.

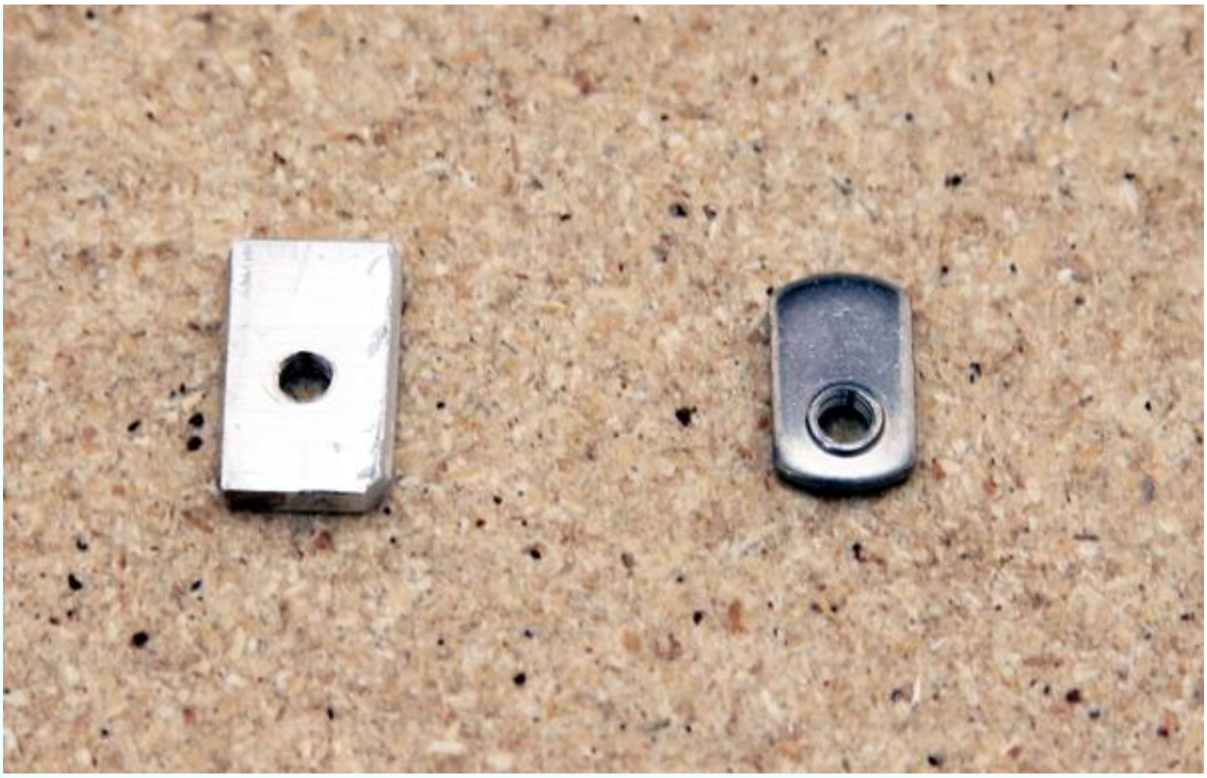


Figure 3-49. Two launch button nuts, one homemade and one commercial.

Start by drilling a hole near the end of the aluminum rod. Spray a bit of cooling lubricant, like WD-40, while drilling the hole. Using lubricant again, carefully tap the hole with the 8-32 tap (Figure 3-50).

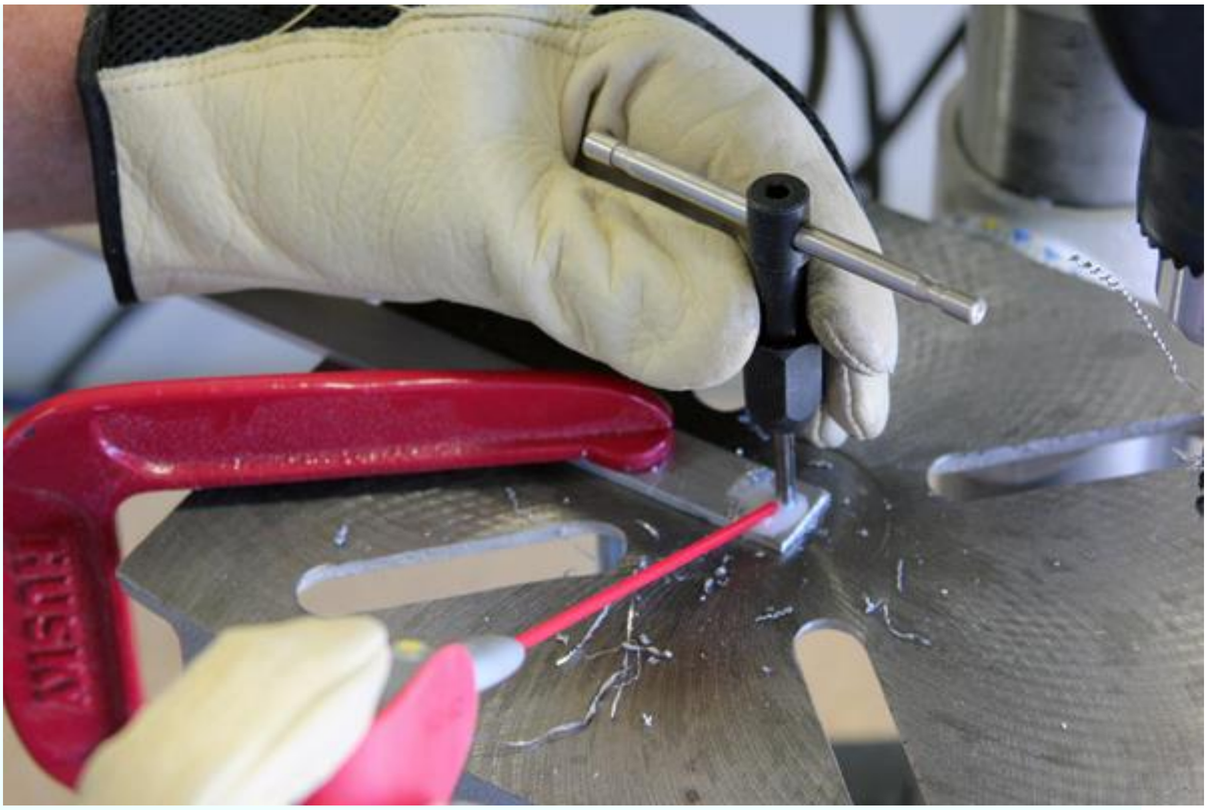


Figure 3-50. Using lubricant, drill and tap a hole near the end of an aluminum rod.

Once the hole is drilled, cut the nut from the bar using a cutoff saw or a Dremel tool with a metal cutting wheel (see Figure 3-51). You may need to sand the corners a bit on a belt sander to remove rough edges. Whether you make your own nut or buy one, be sure to scuff the surface with medium grit sandpaper. You’re going to glue the nut in place, and you want the glue to stick.

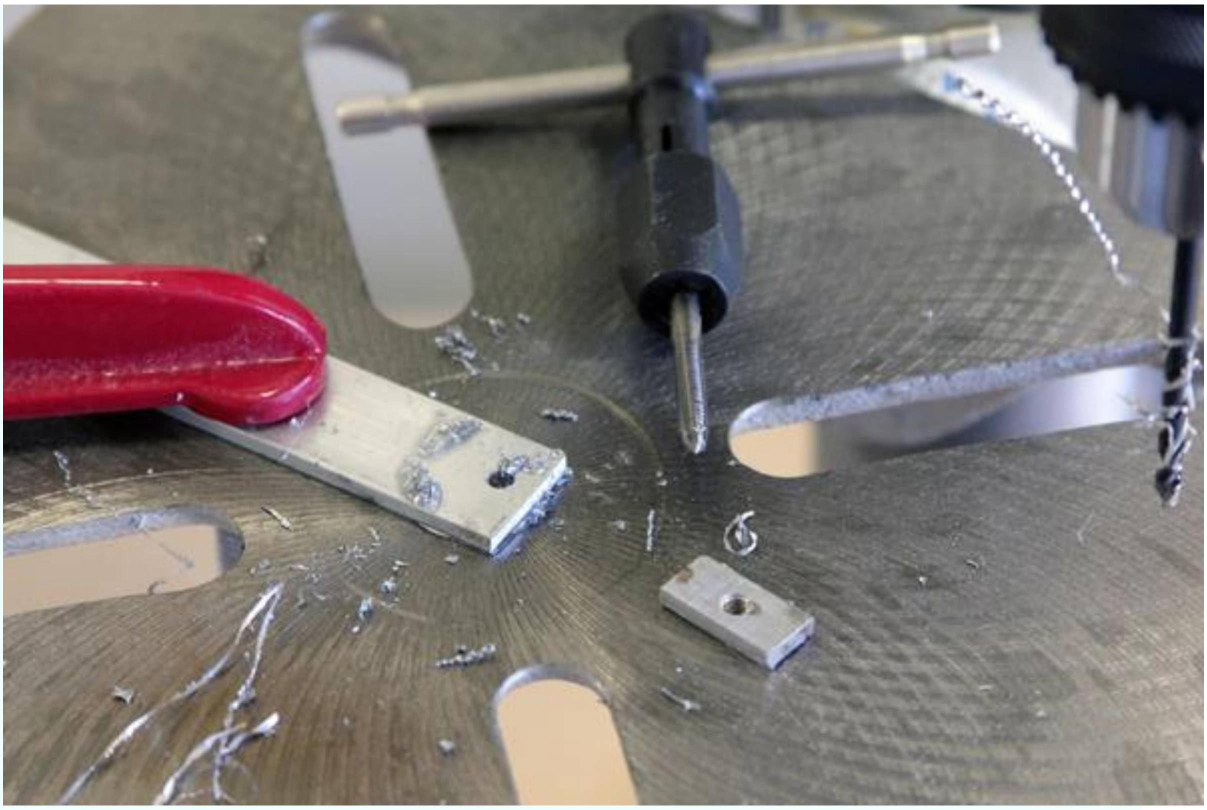


Figure 3-51. Cut the nut from the end of the bar.

Back when you marked the airframe for the fin slots, you also marked lines along the entire length of the airframe tube for rail guides and launch lugs. Using one of these lines as a guide, drill a 3/16” hole 4” from the front end of the rocket and another 1” from the aft end of the rocket (see Figure 3-52). You can cut the hole with a hobby knife if you are careful.

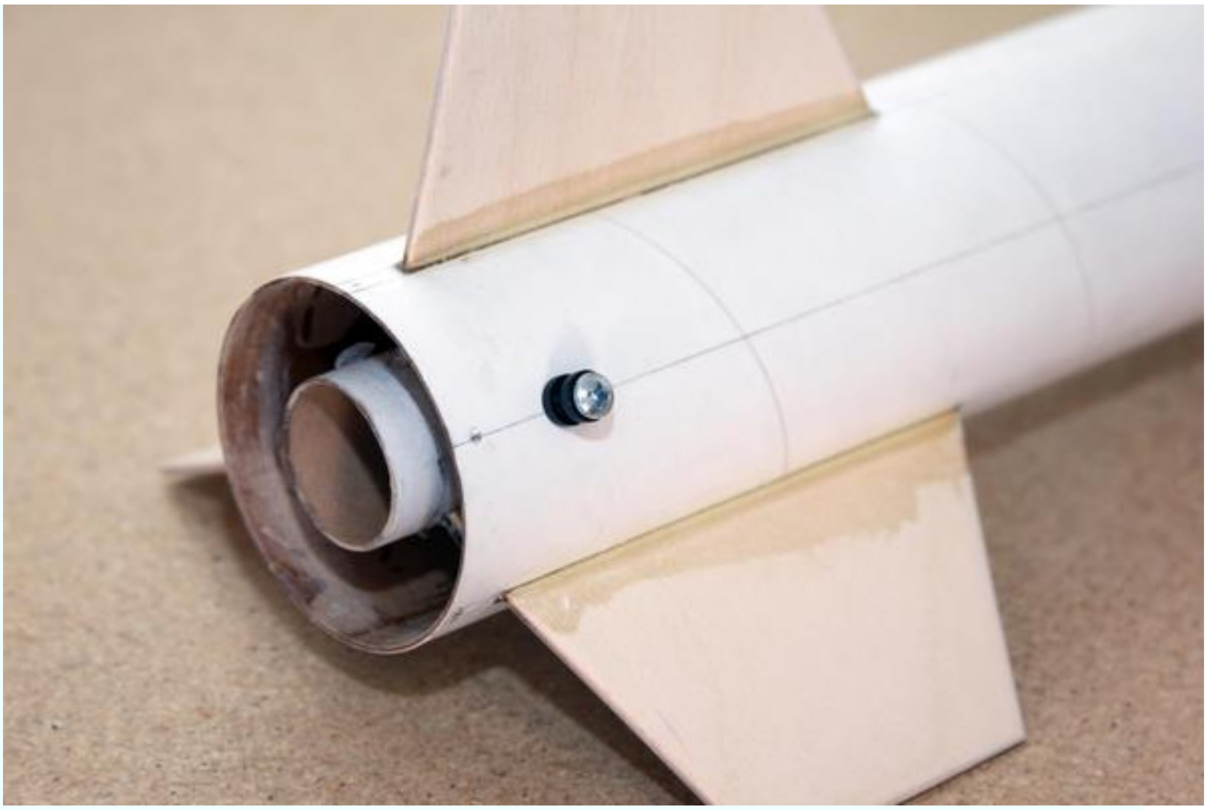


Figure 3-52. Install one rail button 1” from the aft end of the rocket, and another 4” from the front of the airframe.

Clean any oil or grease from the nuts with rubbing alcohol, and then apply a small amount of oil or grease to the threads to protect them from the glue. Apply some epoxy glue to one of the nuts and glue the nut to the inside wall of the airframe tube, right under the hole in the aft end of the tube. Screw in the rail button bolt to make sure the nut is in the right spot and flat against the wall. Remove the bolt after about 5 minutes. The epoxy will have gelled, but even if some got on the bolt, it will still be soft enough to allow you to work the bolt free. Repeat this process for the button at the front of the rocket.

After the glue dries, screw the launch buttons in place. Shine a flashlight into the front end of the rocket and look at the bolt sticking out beyond the nut. This bolt is very likely to snag your parachute as it is ejected from the rocket, causing the parachute to get stuck in the body tube. Mark the bolt so you know how much is sticking out, remove the rail button, and cut off the excess part of the bolt. Use a belt sander or grinding wheel on a Dremel tool to smooth out any rough edges so the bolt screws into the nut, then reinstall the launch button. Use a small dab of Loctite to keep the screws from working loose under the vibration of rocket flight.

Launch lugs come in many forms. LOC Precision sells heavy paper lugs that will work just fine for Callisto. I used 5/16” aluminum tube cut to 2” lengths. Brass tube works well, too. It’s more a matter of what you find at the hardware store than anything else. If you use brass or aluminum tube, cut two 2” lengths from the tube and clean up the edges with sandpaper or a grinding wheel on a Dremel tool.

Using 5-minute epoxy, glue one launch lug 4” from the front of the body tube and the other 2” from the aft end. Check these tubes very, very carefully to make sure they are lined up perfectly. I check them visually when they are glued in place, and then slide a 1/4” rod through the launch lugs after about 10 minutes to make sure they are aligned. While the epoxy glue will be pretty tacky after 10 minutes, it’s not too late to pop a launch lug off and reglue it.

Installing the Aft Centering Ring and Motor Retainer

Dry fit the aft centering ring and motor retainer to make sure you’ve cleaned up any stray epoxy well enough for the centering ring and motor retainer to slide into place. Chip excess glue off with a hobby knife or sand it with medium grit sandpaper if the fit isn’t quite right.

Once you are satisfied with the fit, apply a generous amount of 5-minute epoxy just inside the airframe tube and around the outside of the motor mount tube, and then slide the aft centering ring all the way in until it sits against the base of the fins (Figure 3-53). Stand the rocket upright until the glue gels.

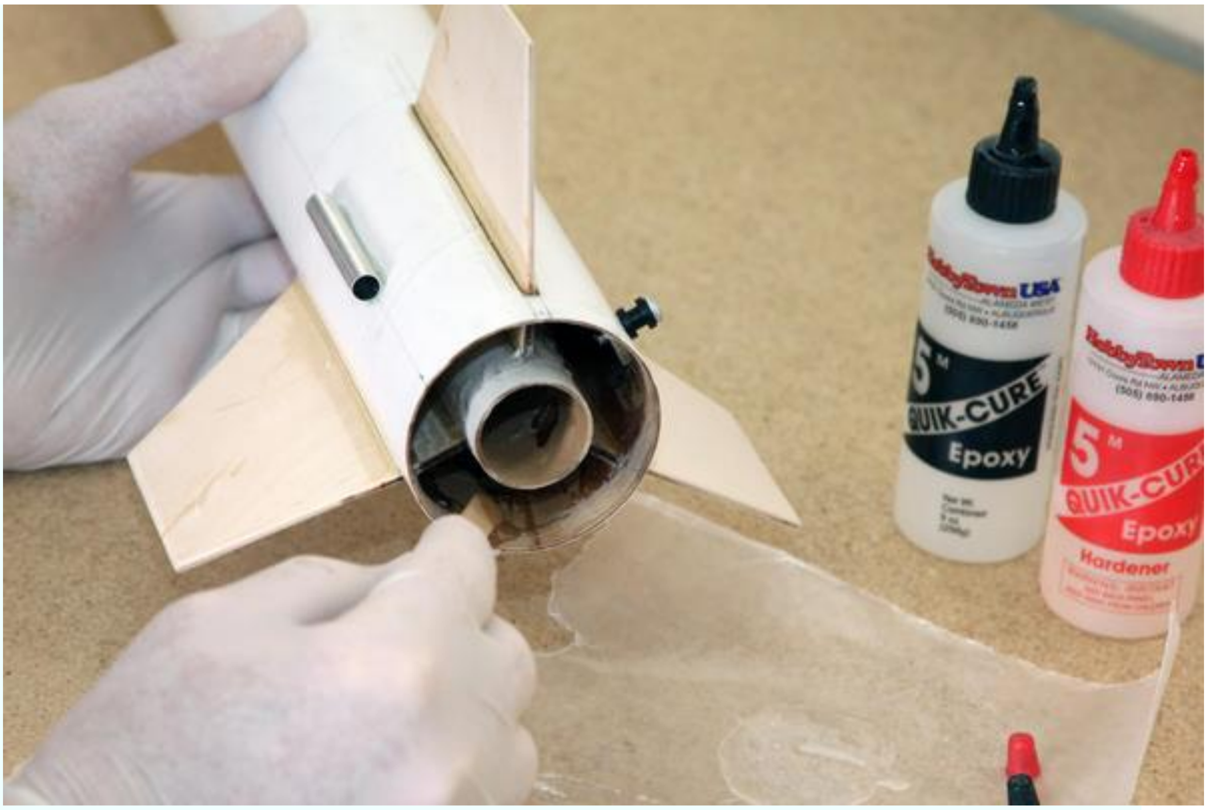


Figure 3-53. Smear a generous amount of glue inside the airframe tube, then slide the centering ring all the way against the fins.

Apply a fillet of 5-minute epoxy around the joint between the centering ring and the airframe tube. Do not apply a fillet where the centering ring touches the motor mount tube! See Figure 3-54. Stand the rocket upside down while this glue gels.

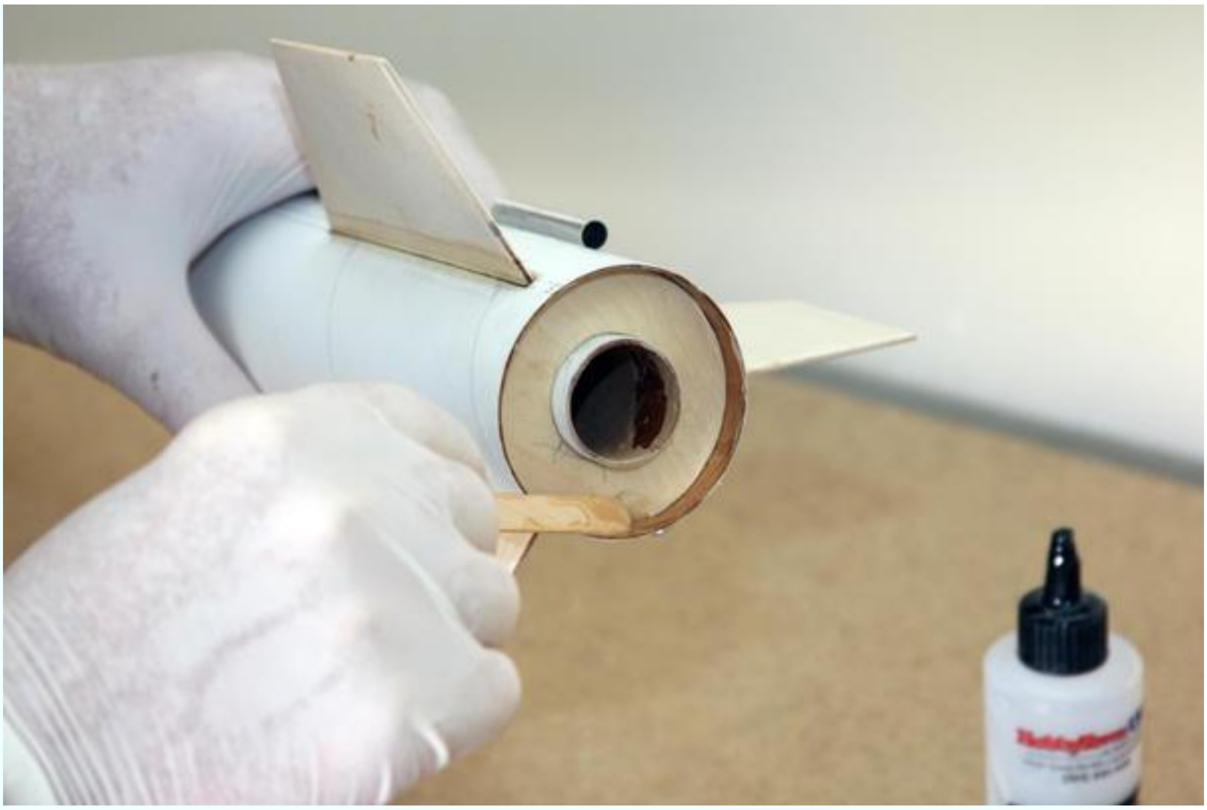


Figure 3-54. Apply a glue fillet where the centering ring touches the airframe, but not where it touches the motor mount.

The last construction step at the back of the rocket is to install the motor retainer. Scuff up the inside of the motor retainer with medium grit sandpaper to give the glue something to adhere to. Mix a small amount of JB Weld or a similar heat-resistant epoxy and smear it over the part of the motor mount tube that is sticking out beyond the rear centering ring (See Figure 3-55). Slide the motor retainer into place and clean up any excess glue with a paper towel soaked in rubbing alcohol.

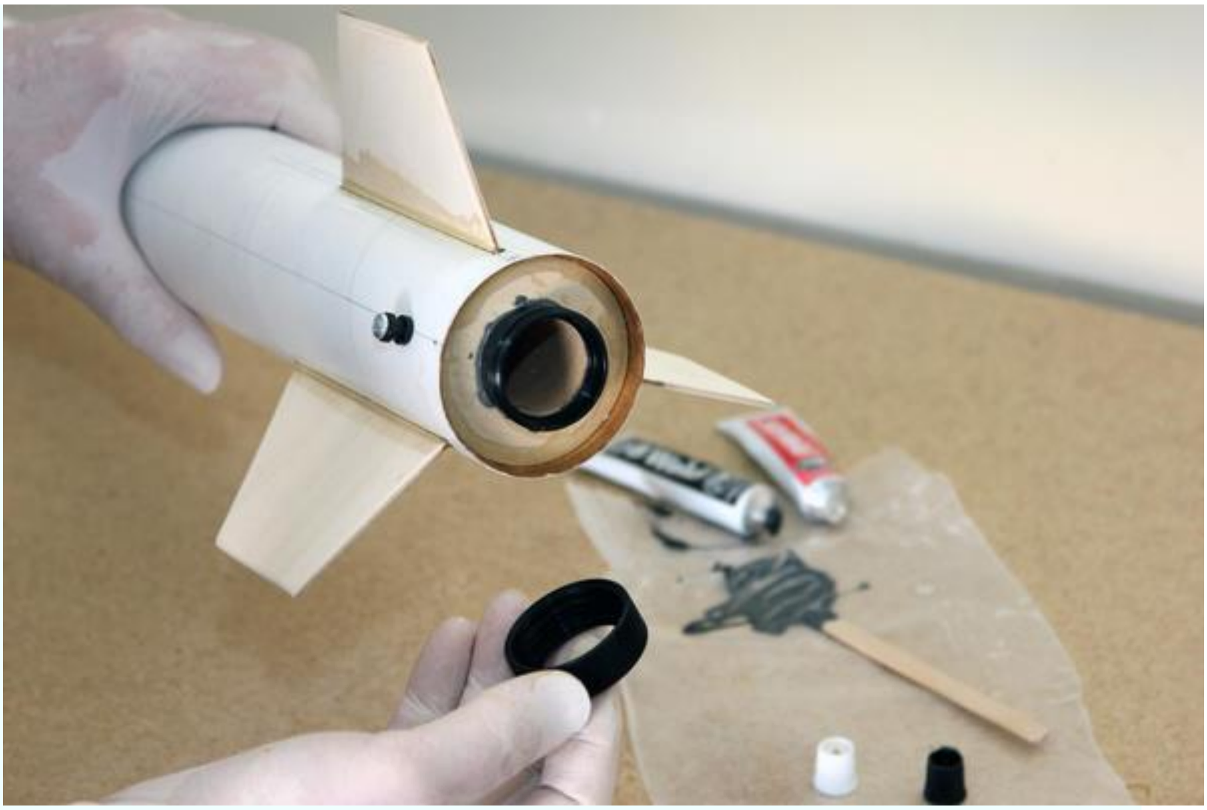


Figure 3-55. Install the motor retainer using JB Weld or some other heat-resistant epoxy.

Installing the Quick Links

Unfurl that shock cord that has been getting in the way during this entire phase of the construction process. We're going to attach the quick links that will eventually be used to attach the parachute and payload bay.

Attach one quick link to the loose end of the shock cord. Some people use a hangman's knot with three or four loops; I prefer using a buntline knot, as shown in Figure 3-56.

Fold the exposed part of the shock cord in thirds. Find the fold that is 1/3 of the way from the loose end of the shock cord and tie a simple overhand knot. Attach the second quick link through this hole. This is where the parachute will attach. Placing the quick link 1/3 of the way from the end, rather than in the middle, keeps the payload bay and rocket from banging into each other while the rocket descends.

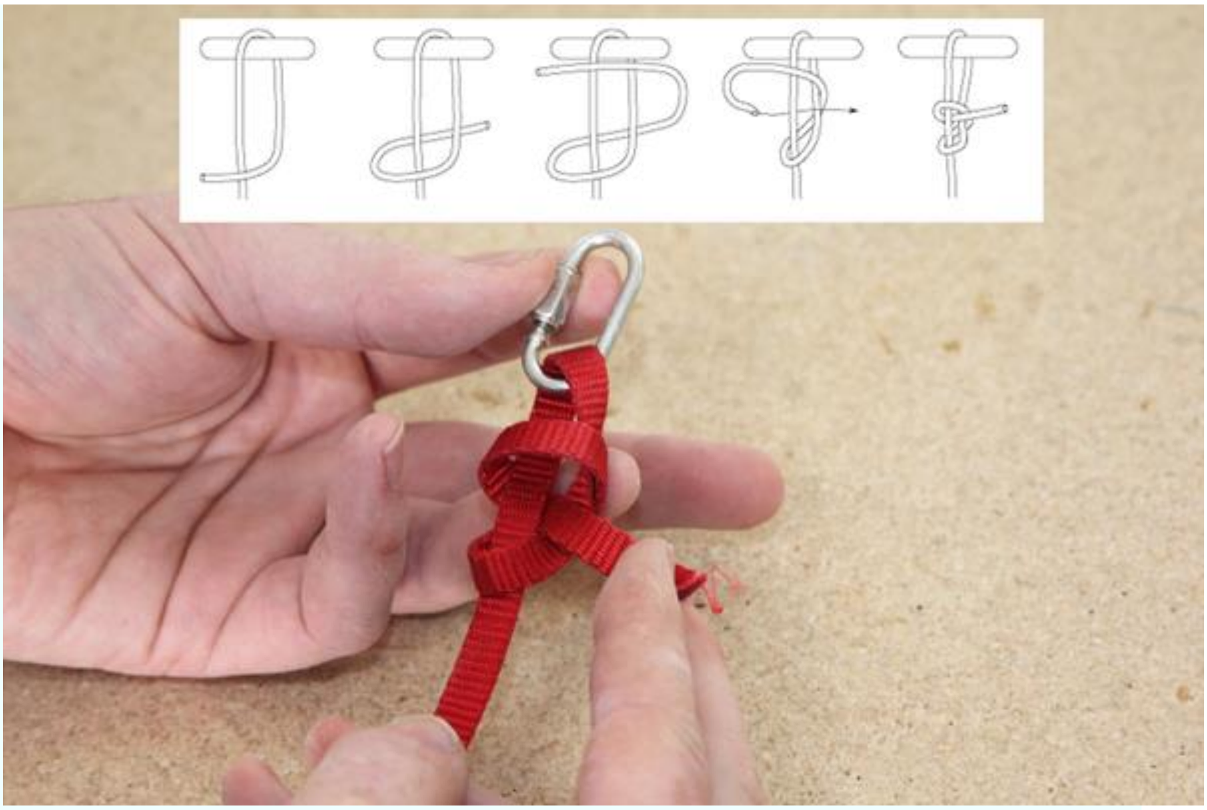


Figure 3-56. The buntline is a great knot for attaching the shock cord to the end quick link.

Apply a small dab of 5-minute epoxy where the end of the nylon shock cord sticks through the last part of the buntline knot. You’re not trying to use the glue to strengthen the knot—the nylon is stronger than the glue joint—you’re trying to make sure the knot doesn’t slip or vibrate loose. Knots tend to tighten up and get stronger under tension, but slippery nylon can work loose when the knot is slack. The finished knots with quick links attached are shown in Figure 3-57.

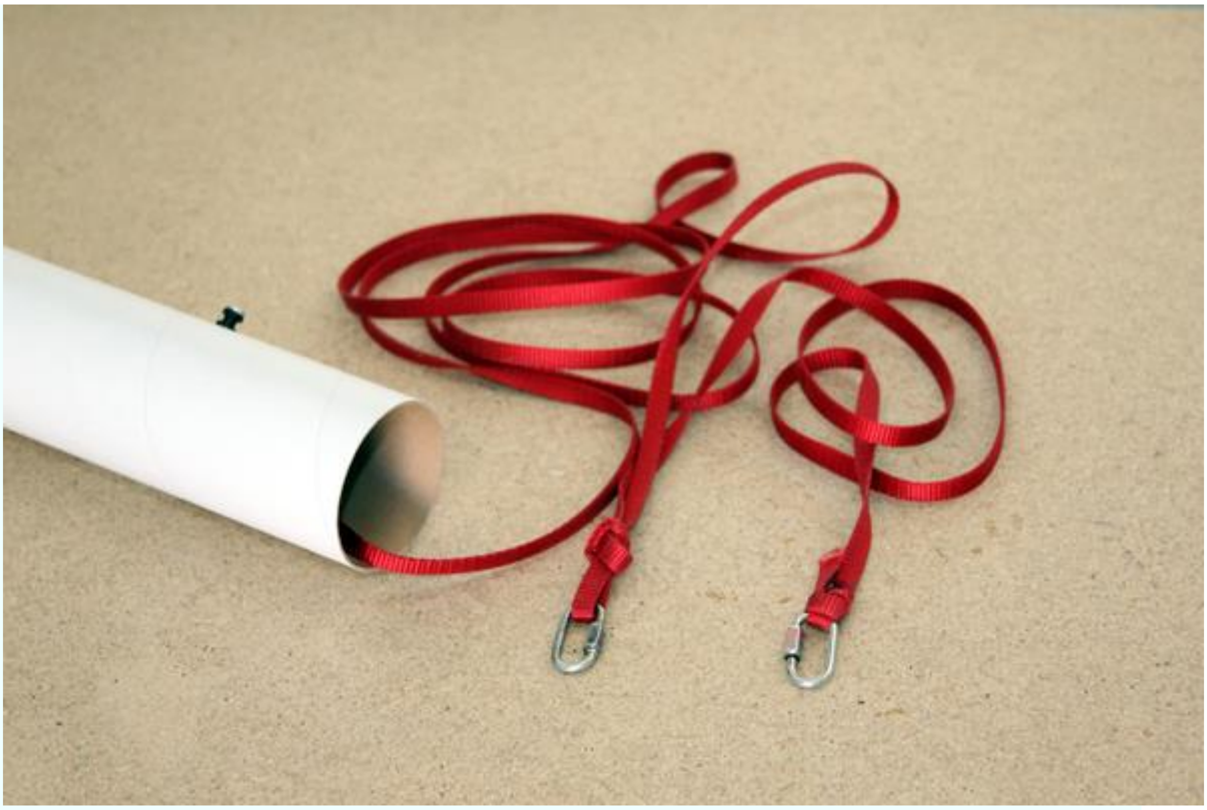


Figure 3-57. Attach one quick link to the end of the shock cord and the other about 1/3 of the way from the end.

Building the Payload Bay

The payload bay consists of a 10”-long section of body tube, a 6”-long tube coupler that slides into the body tube, a bulkhead to block the base of the payload, and an eye bolt with a washer and nut. LOC Precision sells all of the parts in a nice kit, or you can buy the parts separately and build your own.

Attach the eye bolt through the bulkhead, then use 5-minute epoxy to glue the bulkhead in place (see Figure 3-58). Leave a 1/4” gap at the bottom of the tube coupler so there is room for a generous glue fillet. I also add some epoxy to the eye bolt so it won’t work loose. Follow the same procedure you used on the main part of the rocket, applying a fillet and standing the part up while the fillet gels.

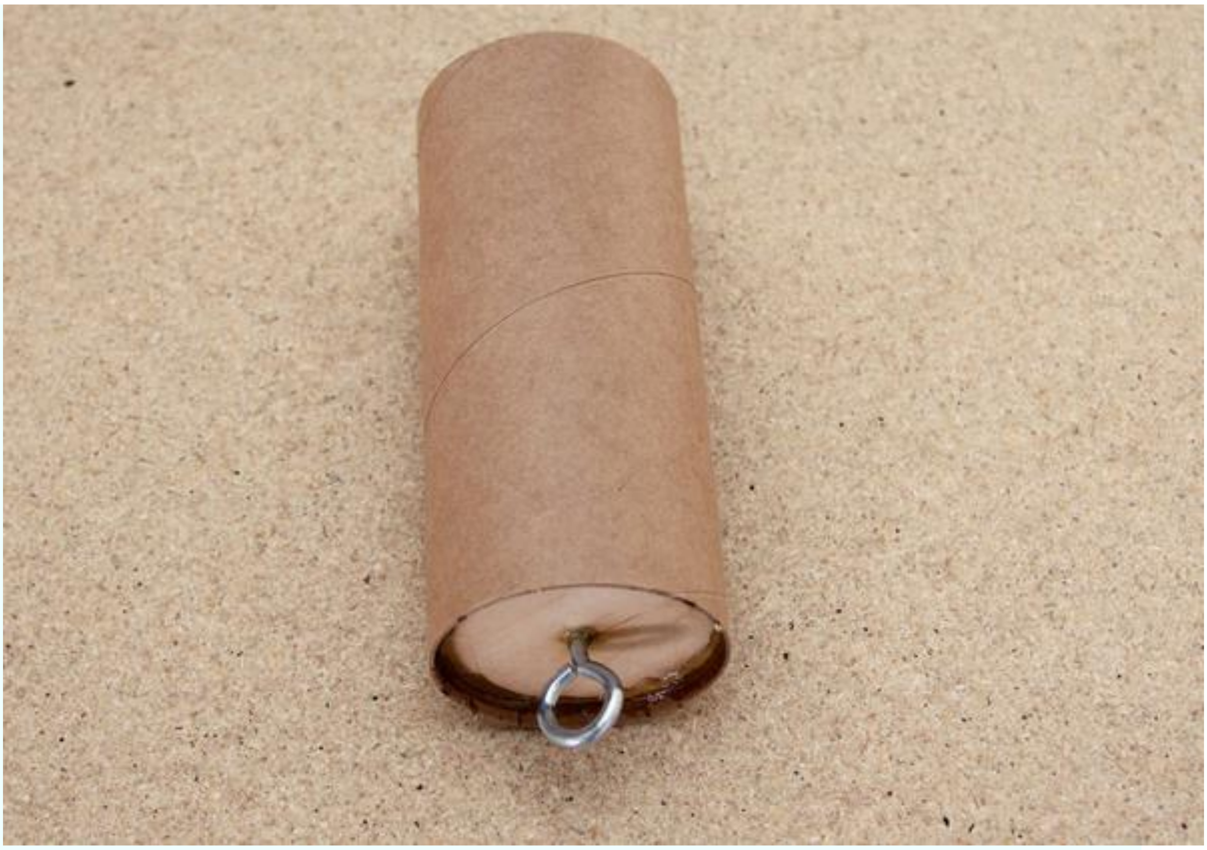


Figure 3-58. Attach the eye bolt, then glue the bulk plate 1/4” from the bottom of the tube coupler.

Apply a thin layer of 5-minute epoxy to the inside of the payload bay tube. Slide the tube coupler assembly 3” into the body tube (see Figure 3-59). The eye bolt should be on the bottom of the assembly. It’s OK to slide it in a little more or less. Be sure to leave at least 2 1/2” sticking out, though. As a general rule, you want a length at least equal to the diameter of a tube at the base of a nose cone or tube coupler, so it stays in place without wobbling.

Take a look at the nose cone. There will be a line of *flash,* a little ridge of plastic left over from the molding process. This needs to come off. Using a hobby knife, scrape this area until it is smooth. You aren’t trying to cut the flash off; that would likely leave small gouges in the nose cone. Instead, hold the blade vertical or pointed slightly away from the direction you will scrape the nose cone, as shown in Figure 3-60.

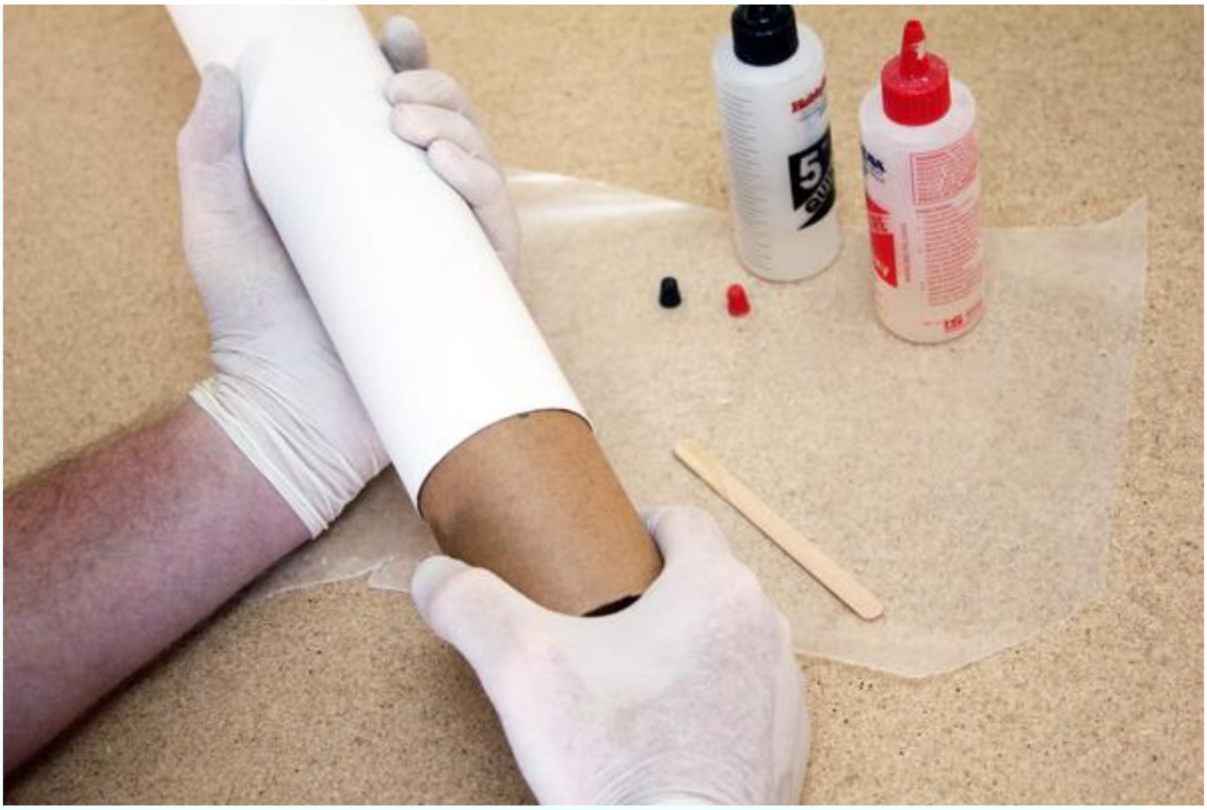


Figure 3-59. Glue the tube coupler into the 10” payload bay tube so 3” of the tube coupler sticks out.

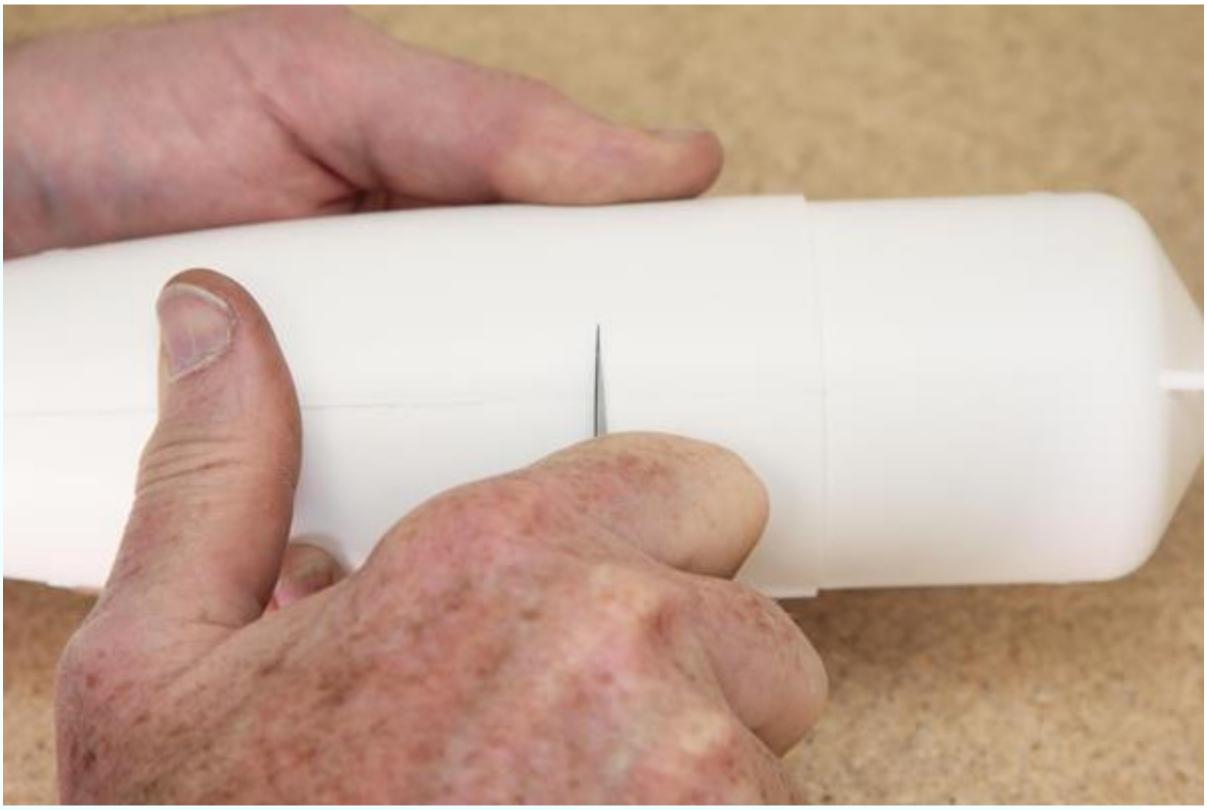


Figure 3-60. Scrape any flash from the nose cone.

Slide your fin template onto the end of the payload tube and use it to mark the spots for three screw holes. They should be evenly spaced around the payload tube and 1” from the end the nose cone slides into. Insert the nose cone and drill three 3/32” holes through both the payload tube and nose cone. Use three 1/2”-long #4 pan head wood screws to fasten the nose cone into the payload bay (see Figure 3-61). You can find these screws at almost any hardware store or order them online. This makes sure your payloads stay put inside the payload bay rather than popping out and returning on their own ballistic trajectory.

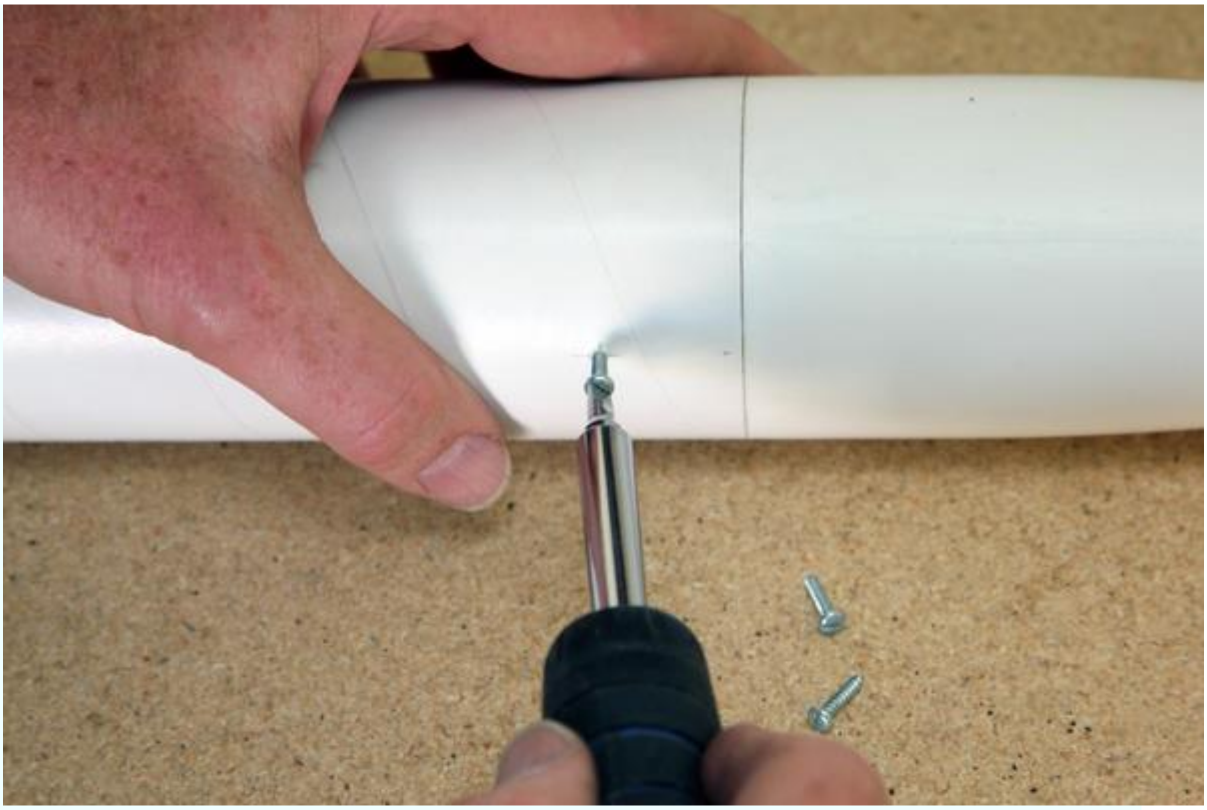


Figure 3-61. Fasten the nose cone to the payload bay with #4 screws.

It’s unlikely you will get the holes exactly 1/3 of the way around the tube, so rotating the nose cone by 120° generally won’t line the holes in the body tube up with the holes in the nose cone. If they do match, great—you’re a lot more accurate than I am. In general, though, I use a permanent marker to place the letter A next to one of the holes in the nose cone, and on the inside of the body tube above the matching hole in the payload bay. That takes the guesswork out of lining up the holes when I’m installing a payload.

Painting Callisto

When you go to a launch, you will see a lot of high-power rockets that are not painted, especially the larger ones made from plastic and fiberglass. While that works, there are several good reasons to paint your rocket.

First, the paint adds some protection. That's especially true for a paper rocket that may be flown in damp conditions. If the rocket spends any time lying in a damp field while you walk out to recover it, the water could soak into the paper tube and weaken it.

A very good paint job can also cut the drag on a rocket by quite a lot. How much? Well, flying on an H128 motor, OpenRocket estimates Callisto will fly to an altitude of 2,002 ft with no paint. Add a filler to the fins and a coat of spray paint, and the estimate jumps to 2,163 ft. If you take the time to create a finely polished paint job, just like you would find on a car, the altitude prediction jumps to 2,442 ft. Your rocket will go about 8% higher with a plain paint job, and 22% higher with a nicely polished paint job!

Paint can also make your rocket more visible, making it easier to see both in the air and on the ground.

Still, the main reason for painting your rocket is that you don't want to be one of "those" people. You know. The ones with an ugly rocket.

Finishing starts by preparing the surface. Sand any rough epoxy at the fin fillets, and carefully trim off any epoxy that ended up where you didn't intend. Use fine sandpaper to sand the nose cone to rough it up a bit so the paint will stick, and to sand the fins so they are nice and smooth.

Apply some sort of filling primer. I like to spray on Rust-Oleum 2in1 Filler & Sandable Primer. Be sure you spray the entire rocket, including the airframe tubes. This stuff goes on thick. After it dries, sand with fine sandpaper until you start to see the material under the primer. You're not trying to weigh the rocket down with primer, you're trying to smooth out the imperfections. Repeat this process until the rocket feels silky smooth, and a very light final coat of primer does not show any imperfections.

You can use a paintbrush, but I generally prefer spray paint. Enamel spray paint works really well, but you’re stuck with the selection of colors the manufacturer decides to offer. An alternative is acrylic paint applied with an airbrush. An airbrush will cost more in the short run, but it will pay off in the long run, both in reduced paint cost and because you can mix your own colors.

If you intend to use a multicolored paint scheme like the one for Callisto, start with the lightest color. After it dries, mask off the areas that are supposed to stay this color using a good-quality painter’s tape. Add a light coat of the original, light color. That’s because all tape will bleed to some extent, and you want it to bleed with the original color. Finally, add the next color.

Acrylic paint tends to have a flat or satin finish, not a high-gloss finish. If you apply decals, they can easily come off if the rocket gets damp. An optional final step that solves both problems is to lightly spray the entire rocket with clear enamel. Apply two to three very light coats, not one heavy one. Even if you use acrylic rather than enamel, a heavy coat of clear enamel paint will cause the colors to bleed.

That’s enough to give your rocket a nice colorful, protective finish. I don’t generally recommend putting in the work to create a highly polished paint job unless you are trying for extreme altitude. Still, if you want a polished surface, the next step is to spray on several light coats of clear enamel, then sand with progressively finer sandpaper, finishing off the rocket with a polishing compound. You can find the supplies and instructions at stores that specialize in auto painting.

Tuning the Simulation

Back at the start of Chapter 2, you created a detailed simulation of Callisto. Perhaps you made some changes to the design. In any case, you checked several things about the rocket to make sure the design was sound. But do you remember the parable of the nose cone? Not only were the values in the database slightly wrong, but I mentioned that my own nose cone was a bit heavier and had a slightly different center of gravity than the one in the simulation. Perhaps it was a small difference in the way the nose cones were manufactured, or the values given by the manufacturer were a little off, or the paint I added made a difference. It may have even been some combination of these factors. In any case, it wasn't right.

Guess what? Your finished rocket won't match the simulation exactly, either. It's time for a reality check.

The simulator does as good a job at figuring out the center of pressure as anything short of a wind tunnel. It's probably not perfectly correct, but unless you have access to a wind tunnel, you will have to trust that value.

The overall weight of the rocket is sort of important, but not too critical. If you have a kitchen scale, by all means, weigh the rocket to get the correct value. If your real rocket is heavier than the design, you can add weight to the simulated rocket by adding a mass component. On the other hand, if your rocket somehow weighs less, you can remove weight by using the Override tab on any of the components. The Override tab lets you change the mass or center of gravity from the calculated value to whatever you like. The overall weight of the rocket really won't have much of an impact on the flight profile unless it is way off of the calculated value, though. You shouldn't worry about it too much unless you are trying to get the most accurate simulation possible for a contest.

When weighing the rocket, be sure to include the parachute, parachute protector, and anything else you plan to have on the rocket when it flies (except the motor). In my case, the rocket weighed 23 1/8 oz. I added a 6.1 oz mass component called "As Built Adjustment" to the payload bay to account for the extra weight.

There is one value that is really important, and it's also very easy to measure. You can find the actual center of gravity by simply balancing the rocket on your finger, as you see in Figure 3-62. Be sure to find the center of gravity with the parachute, shock cord, and parachute protector in place. You don't need a motor; the simulator can add that. Measure the center of gravity from the front tip of the nose cone. On my rocket, the measured center of gravity was 27 1/2" from the tip of the nose.

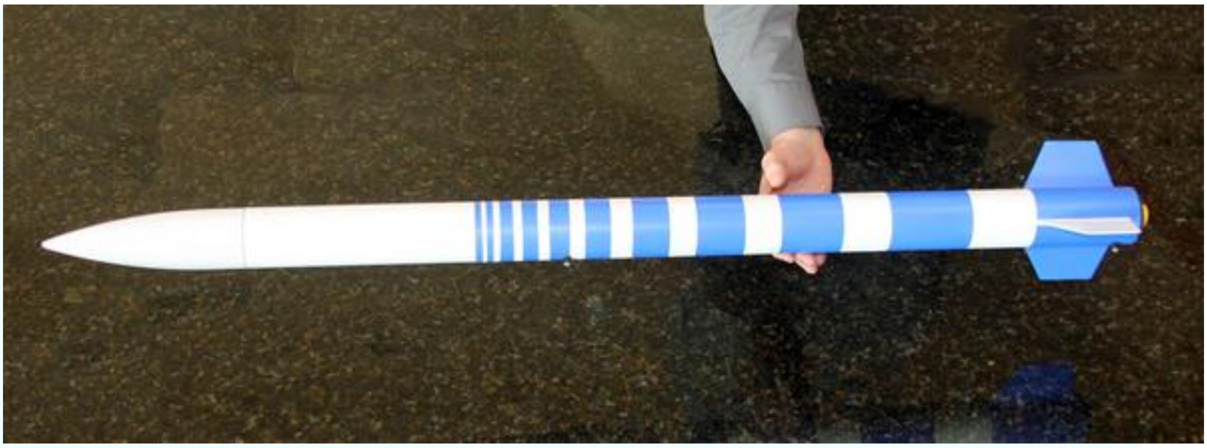
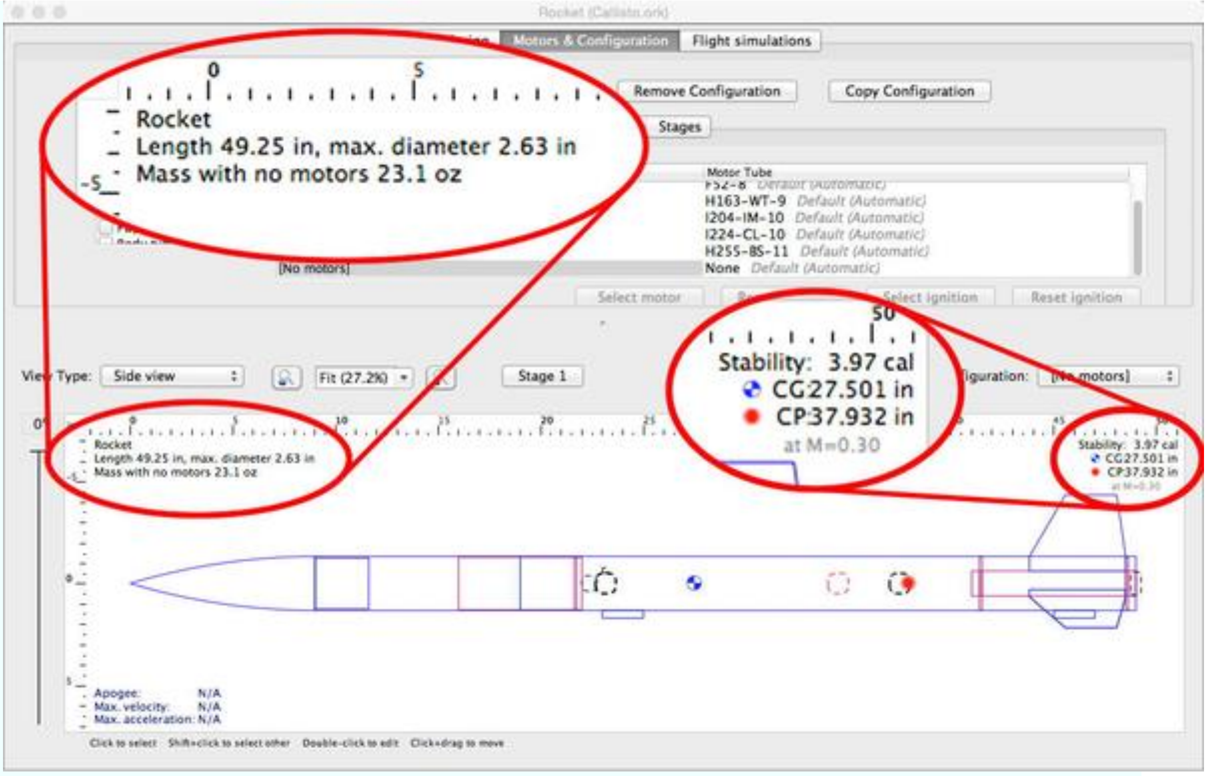


Figure 3-62. Measure the actual center of gravity by balancing the rocket on your finger.

You need to compare this to the center of gravity as calculated by the simulation to make sure they are close. Since you didn't find the center of gravity with a motor installed, you need to find it the same way on the simulation. Go to the Motors & Configuration tab and add a new configuration with no motor. Selecting a configuration with no motor will remove the motor from the calculations shown in the main window. Check the location of the center of gravity. Is it the same as the one you measured? Mine wasn't. I slid the weight adjustment from the last step back 13.67" from the top of the payload tube to account for the difference. My results are shown in Figure 3-63.



F52-8 Default (Automatic)
H163-WT-9 Default (Automatic)
I204-IM-10 Default (Automatic)
I224-CL-10 Default (Automatic)
H255-BS-11 Default (Automatic)
None Default (Automatic)

Rocket
Length 49.25 in, max. diameter 2.63 in
Mass with no motors 23.1 oz

Stability: 3.97 cal
CG 27.501 in
CP 37.932 in
at M=0.30

Apogee: N/A
Max. velocity: N/A
Max. acceleration: N/A

Figure 3-63. Add or remove weight, sliding mass objects around, until the values for mass and center of gravity match measured values for the real rocket.

Once the center of gravity without a motor matches reality, select the various motors you might want to use in this rocket and check the stability. It's at the right of the rocket plan pane, circled in red in Figure 3-63. This must be 1 or larger for all motors. If it's not, the rocket might still be stable, as long as the stability is positive. Still, no one will believe you without a wind tunnel test or flight data to prove your point. By far the easiest thing to do if the stability factor is less than 1 is to add weight to the nose until it is greater than 1. You can do that by adding a payload or by dropping fishing weights into the nose cone, followed by some epoxy glue to keep the weights in place.

Your last step is to use the simulator to find the center of gravity with the motor you intend to use for your Level 1 certification loaded into the rocket. Load the motor in the Motors & Configuration tab. Read the value from the simulator. Measure this out on your rocket and put a piece of tape at the location. Mark it with the symbol you see in the simulator: a circle with two of the quarters colored in. Do the same for the center of pressure, using the circle within a circle symbol you see in the simulator.

Chapter 4. The Level 1 Certification Flight: Preparations

Now that you've built Callisto (or another rocket that can fly on an H or I motor), it's time for the Level 1 flight. This chapter along with the next will guide you through the process of flying Callisto for a Level 1 certification. We'll review the various rules concerning getting your certification, building a motor, getting the rocket ready to fly, and the Level 1 certification flight. With minor, obvious changes, the information in this chapter will work for any Level 1 rocket.

You can also fly Callisto on an F or G motor. The process is essentially the same, but a Class 2 FAA clearance is not required for F or G motors. You do still need an FAA clearance if you are using an ammonium perchlorate motor, but it's a Level 1 clearance, which is much easier to get. We'll take a look at the clearance types in Chapter 11. Mid-power motors also cost less per flight. The rocket won't go as high, which is very nice on a breezy day. Finally, a mid-power motor gives you a chance to try Callisto before the certification flight.

For the most part, flying Callisto on an F or G motor proceeds just like flying it for your Level 1 certification. The only real difference is that the Class 1 FAA clearance is easy enough to get that you might decide to fly Callisto on your own. That means setting up and running your own launch site. While that is not difficult, you should give it some thought, especially choosing an appropriate location. You've probably seen people flying small rockets from parks, athletic fields, or open lots. That's appropriate for low-power rockets, which are typically built from thin, collapsible paper tubes, balsa wood fins, and lightweight nose cones. (In one test, a low-power rocket was aimed at a plate glass window. The rocket collapsed, but the window was fine.) Low-power rockets are perfectly safe in an urban park or field. The same is not true for Callisto, though. Weighing in at nearly 2 pounds, built from thick paper tubes, plywood fins, and a heavy plastic nose cone, Callisto has the potential to do some real harm if it gets out of control. You need to keep that in mind when picking a launch site. It should be at a safe distance from large groups of people, and all of the people in the area need to be aware that a launch will occur. You also need larger fields to fly mid- and high-power rockets. There are specific minimum field sizes that we will cover later, in Table 5-1, but always keep in mind that those are *minimums*. A larger field is always better, both for safety and to increase the chance of you finding your rocket.

So, even if you decide to fly Callisto on a mid-power motor, I'd recommend attending a high-power launch the first few times you fly the rocket. It will be held at an appropriate place where you can learn from experienced flyers who know how to run a safe launch operation. You might want to fly Callisto on your own later, but the experience you get at the high-power launch will help you do that safely.

Getting Ready

Long before launch day, you should get in touch with your local club to find out how they handle certifications. If possible, meet with the person who will handle your certification to discuss preparations.

The certifying official will almost certainly ask you to get your paperwork ready before the launch. You can ask them what launchers will be available and whether they have launch rods or launch rails. You will need to check the altitude restriction for launch day. Make sure it is at least 10% higher than your simulated maximum altitude. Finally, you can ask about anything you might need help with, such as ordering a motor, or get answers to any questions you have. You are about to launch a 1 1/2 pound missile into the air at over 400 miles per hour—more than half the speed of sound! Be sure you know what you are doing. Ask questions about anything you are unsure of.

Following the Rules

There are a few rules you must follow for your Level 1 flight. Your certifying official will make sure you follow them, but it helps to know what they are beforehand.

You must be at least 18. There is a provision for a junior Level 1 certification for those over 14; we'll cover that in a moment.

You must personally build the rocket you will fly for the certification. It can be a kit or you can scratch build a rocket. Building Callisto is considered scratch building the rocket, since it involves buying all of the parts separately and assembling them based on your own simulation of the rocket. The rocket itself needs to be a fairly normal rocket, like Callisto; one that has fins for guidance and a parachute for recovery. NAR also allows streamers, helicopter recovery, or any other method that physically changes the configuration of the rocket to ensure it lands safely.

TRA requires that you use a single H or I motor for the flight. NAR allows clusters, but there must be at least one motor that is an H or I motor. Some motors are pretty close to the boundary between G and H, or I and J. The manufacturer’s test might even give a different letter group than the testing done by NAR or TRA. In all cases, the letter listed on the motor by the manufacturer is used to determine if the motor is an H or I motor, regardless of test data that might show the motor is slightly over or under the range for that designation.

Most high-power motors will require some assembly, although there are a few that are completely prepackaged. If your motor requires any assembly, your certifying official needs to see you build the motor yourself. Part of the reason is to make sure you know how to build the motor; part of the reason is to make sure you build it right. Leaving out an O-ring or putting it in the wrong place can cause the motor to explode. Sometimes this will happen even on a properly built motor. When it does it’s called a *CATO*, a slang term for catastrophic failure.

Later in the book we’ll cover several kinds of electronics packages for rockets. Some are radio trackers that emit a signal you can track using a directional antenna, or GPS systems that broadcast the rocket’s location back to your computer or smartphone. Some are electronic deployment devices that track the altitude of the rocket, deploying the parachute at apogee. There are also dual-deploy recovery systems, where the rocket deploys a small parachute or streamer, or otherwise simply pops apart at apogee and then deploys a larger parachute at a low altitude. That helps the rocket land near the launch spot, since it won’t spend as much time in the air, where the wind can carry it away. All of these are allowed on a Level 1 flight, but none are required.

TIP

There are some environments where it is pretty tough to find a rocket, even when you know roughly where it is located. If a rocket lands in a cornfield or tall grass, you might walk just a few feet away from it and never see the rocket.

Take a look at where your certification flight will take place. If it’s a location where a rocket could be tough to find, skip ahead to Chapter 10. That chapter covers a variety of techniques for tracking and finding your rocket. Even a cheap, simple beeper can make it a lot easier to find what you’ve spent so much time and effort to create.

Your certifying official must watch the flight, checking to make sure it goes well. The rocket must stay within the area covered by the FAA waiver, it must be stable, and the recovery system must deploy properly.

After the flight, you need to recover the rocket and bring it back to the certifying official, who will inspect it for damage. There is usually a small amount of damage on a flight, such as chipped paint where the rocket hit a rock on landing. That sort of normal wear and tear is allowed. Basically, the flight is considered successful if the rocket is ready to fly again after changing the motor and performing routine maintenance.

The certifying officials have a lot of latitude in how they interpret and enforce these rules. What they are really asking themselves is if you built a sound rocket, prepared it properly, and flew it safely and successfully.

These guidelines will get you through almost the entire certification process. But there are some other rules the certifying official will use, and they may change from time to time. It’s always a good idea to check the latest NAR rules for the Level 1 flight, and the latest TRA rules. Check the main websites and follow the appropriate links in the event that these links have been changed.

NAR JUNIOR CERTIFICATION

While high-power rocketry is generally only open to those over 18, NAR does have a junior certification program for those 14 to 17 years old. Basically, the junior member must have a certified adult sponsor willing to take responsibility for the junior member's flights. The adult member must build and handle the motor. Other than having an adult present to take responsibility and having the adult handle the motor, the junior certification is identical to the standard Level 1 certification. For details, see the NAR website, or do a web search for "nar junior hpr."

Preparing the Paperwork

You need to file some paperwork with NAR or TRA to actually get your certification. Your certifying official needs to sign that paperwork, so you need to get it ready and take it to the launch site.

NAR LEVEL 1 PAPERWORK

You can download a copy of the current NAR High Power Certification Application from the website. If the link changes, do a web search for "nar high power certification application." It's a two-page form, reproduced in Figures 4-1 and 4-2 for reference.

NAR HIGH POWER CERTIFICATION APPLICATION

APPLICANT INFORMATION (Completed by applicant)

Name: ______________ First ______________ Last ______________ Birth Date ____/____/________

Address: ______________ Street ______________ Apt ______________ NAR No.: ______________

______________ City ______________ State ______________ Zip ______________ Expiration Date: ______________ Is membership current?

Evening phone no.: (____)______________ Cell phone no.: (____)______________ (Optional)

I, ______________________________, certify that I am a member in good standing of the National Association of Rocketry. I am 18 years of age or older. I understand that I must comply with all applicable federal, state, and local laws or regulations during and after this certification attempt.

Signed:______________________________, Date:__________, Location:______________

HPR LEVEL 1 CERTIFICATION CHECKLIST (Certification Team - Use this section Only for HPR Level 1 Certification Attempts)

Preflight:	Motor(s) used: ______________ (At least one motor must be an H or I Impulse Motor)
	☐ Motor is certified ☐ FAA Waiver available (if required) ☐ Safety checklist complete (see back)
Flight:	☐ Model is stable ☐ Recovery system deployed ☐ Safe recovery
Post Flight:	☐ Verify that no major damage is Present Minor impact damage or "zipper" is acceptable
	☐ Verify motor(s) is (are) present **Successful flight?** ☐ Yes ☐ No

HPR LEVEL 2 CERTIFICATION CHECKLIST (Certification Team - Use this section Only for HPR Level 2 Certification Attempts)

Preflight:	Motor(s) used: ______________ (At least one motor must be an J, K or L Impulse Motor)
	☐ Motor is certified ☐ FAA Waiver available (if required) ☐ Safety checklist complete (see back)
	☐ Applicant is Level 1 certified ☐ Level 2 Written Exam passed within one year on ____/____/____ Month Day Year
Flight:	☐ Model is stable ☐ Recovery system deployed ☐ Safety recovery
Post Flight:	☐ Verify that no major damage is Present Minor impact damage or "zipper" is acceptable
	☐ Verify motor(s) is (are) present **Successful flight?** ☐ Yes ☐ No

CERTIFICATION AFFIDAVIT (Successful attempts only, completed by certification team)

We, the undersigned, being members of the National Association of Rocketry distinct from the applicant, have witnessed a demonstration by (Name) ______________ (NAR#) __________, of skills relative to the building and safe operation of High Power Rockets. We attest that the applicant is 18 years of age or older and a member in good standing of the NAR. We believe this member is qualified to build and operate High Power rockets with a total installed impulse up to: ☐ 640 N-sec. (Level 1) ☐ 5120 N-sec. (Level 2)

Name (Printed): ______________ Signature: ______________ NAR No: __________

Birth Date: ____/____/________ Membership Expiration Date: ____/____/________ Certification Level: _____

Name (Printed): ______________ Signature: ______________ NAR No: __________

Birth Date: ____/____/________ Membership Expiration Date: ____/____/________ Certification Level: _____

Cut Along Dotted Line

NAR HIGH POWER CERTIFICATION

Name (Printed): ______________

NAR No.: __________ Cert Level: "1" "2"

Certification Date: ______/______/__________

Witnessed By: ______________

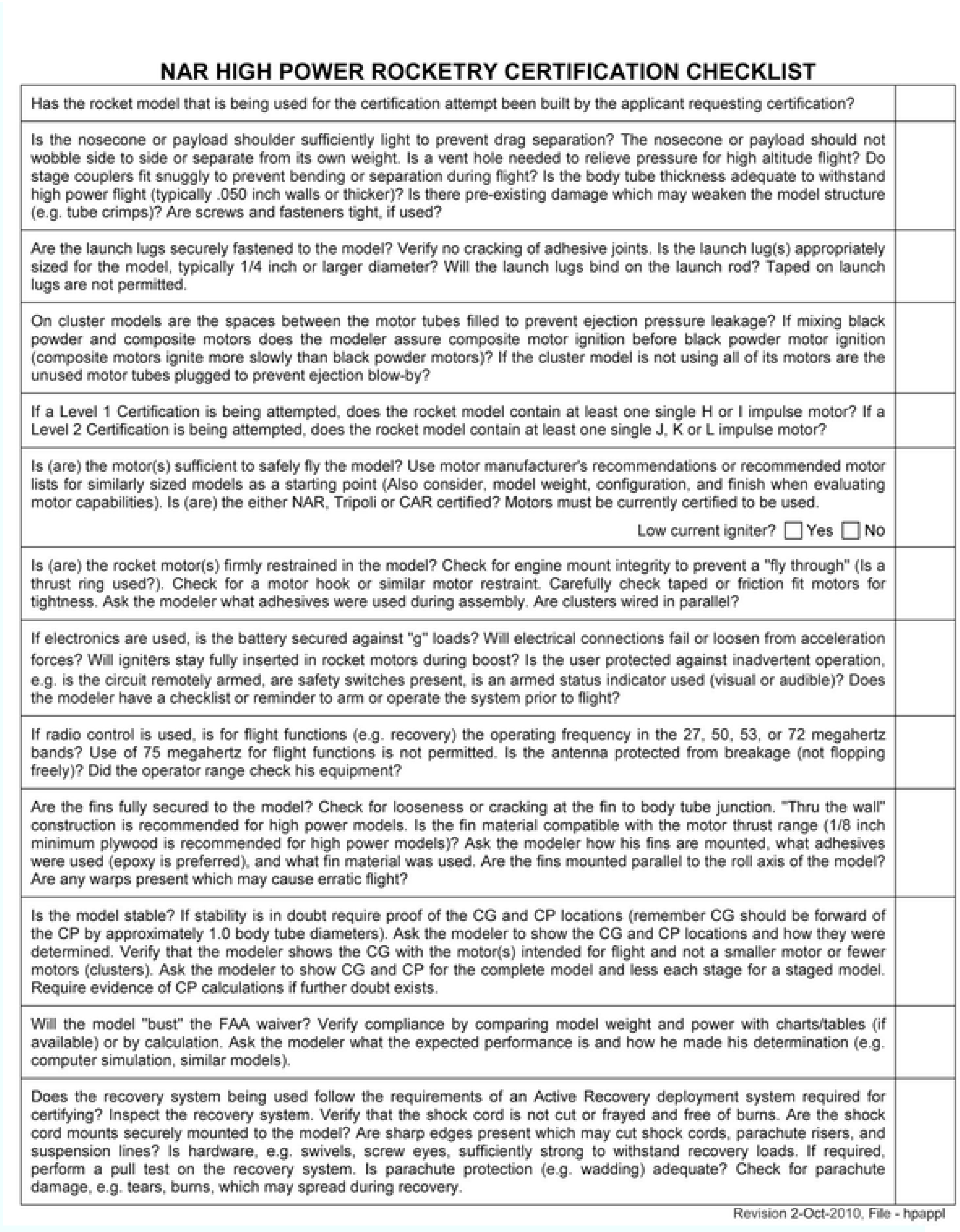
Witnessed By: ______________

This card is void 60 days after Certification Date

1) Request individual Level 2 Written Exams from
NAR HQ
PO Box 407
Marion, IA 52302
Certification Teams or Section Leaders wishing to obtain multiple copies of the of the Level 2 Written Exams can send an email to the current NAR Chairman of Sport Services listed on the NAR Website for a soft copy of the files
2) Send completed forms (with exams, if applicable) to the NAR HQ address listed above

Revision 2-Oct-2010, File - hpappl

Figure 4-1. The NAR paperwork for a Level 1 certification, page 1 of 2.



NAR HIGH POWER ROCKETRY CERTIFICATION CHECKLIST

Has the rocket model that is being used for the certification attempt been built by the applicant requesting certification?	
Is the nosecone or payload shoulder sufficiently light to prevent drag separation? The nosecone or payload should not wobble side to side or separate from its own weight. Is a vent hole needed to relieve pressure for high altitude flight? Do stage couplers fit snuggly to prevent bending or separation during flight? Is the body tube thickness adequate to withstand high power flight (typically .050 inch walls or thicker)? Is there pre-existing damage which may weaken the model structure (e.g. tube crimps)? Are screws and fasteners tight, if used?	
Are the launch lugs securely fastened to the model? Verify no cracking of adhesive joints. Is the launch lug(s) appropriately sized for the model, typically 1/4 inch or larger diameter? Will the launch lugs bind on the launch rod? Taped on launch lugs are not permitted.	
On cluster models are the spaces between the motor tubes filled to prevent ejection pressure leakage? If mixing black powder and composite motors does the modeler assure composite motor ignition before black powder motor ignition (composite motors ignite more slowly than black powder motors)? If the cluster model is not using all of its motors are the unused motor tubes plugged to prevent ejection blow-by?	
If a Level 1 Certification is being attempted, does the rocket model contain at least one single H or I impulse motor? If a Level 2 Certification is being attempted, does the rocket model contain at least one single J, K or L impulse motor?	
Is (are) the motor(s) sufficient to safely fly the model? Use motor manufacturer's recommendations or recommended motor lists for similarly sized models as a starting point (Also consider, model weight, configuration, and finish when evaluating motor capabilities). Is (are) the either NAR, Tripoli or CAR certified? Motors must be currently certified to be used. Low current igniter? ☐ Yes ☐ No	
Is (are) the rocket motor(s) firmly restrained in the model? Check for engine mount integrity to prevent a "fly through" (Is a thrust ring used?). Check for a motor hook or similar motor restraint. Carefully check taped or friction fit motors for tightness. Ask the modeler what adhesives were used during assembly. Are clusters wired in parallel?	
If electronics are used, is the battery secured against "g" loads? Will electrical connections fail or loosen from acceleration forces? Will igniters stay fully inserted in rocket motors during boost? Is the user protected against inadvertent operation, e.g. is the circuit remotely armed, are safety switches present, is an armed status indicator used (visual or audible)? Does the modeler have a checklist or reminder to arm or operate the system prior to flight?	
If radio control is used, is for flight functions (e.g. recovery) the operating frequency in the 27, 50, 53, or 72 megahertz bands? Use of 75 megahertz for flight functions is not permitted. Is the antenna protected from breakage (not flopping freely)? Did the operator range check his equipment?	
Are the fins fully secured to the model? Check for looseness or cracking at the fin to body tube junction. "Thru the wall" construction is recommended for high power models. Is the fin material compatible with the motor thrust range (1/8 inch minimum plywood is recommended for high power models)? Ask the modeler how his fins are mounted, what adhesives were used (epoxy is preferred), and what fin material was used. Are the fins mounted parallel to the roll axis of the model? Are any warps present which may cause erratic flight?	
Is the model stable? If stability is in doubt require proof of the CG and CP locations (remember CG should be forward of the CP by approximately 1.0 body tube diameters). Ask the modeler to show the CG and CP locations and how they were determined. Verify that the modeler shows the CG with the motor(s) intended for flight and not a smaller motor or fewer motors (clusters). Ask the modeler to show CG and CP for the complete model and less each stage for a staged model. Require evidence of CP calculations if further doubt exists.	
Will the model "bust" the FAA waiver? Verify compliance by comparing model weight and power with charts/tables (if available) or by calculation. Ask the modeler what the expected performance is and how he made his determination (e.g. computer simulation, similar models).	
Does the recovery system being used follow the requirements of an Active Recovery deployment system required for certifying? Inspect the recovery system. Verify that the shock cord is not cut or frayed and free of burns. Are the shock cord mounts securely mounted to the model? Are sharp edges present which may cut shock cords, parachute risers, and suspension lines? Is hardware, e.g. swivels, screw eyes, sufficiently strong to withstand recovery loads. If required, perform a pull test on the recovery system. Is parachute protection (e.g. wadding) adequate? Check for parachute damage, e.g. tears, burns, which may spread during recovery.	

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Figure 4-2. The NAR paperwork for a Level 1 certification, page 2 of 2.

You only need to fill out the top portion of the first page. The rest of the form is for the certifying official. I'm sure they will appreciate it if you fill in obvious things, like the motor used and their name, but don't check anything off in the boxes. That's literally a checklist for the certifying official to make sure they do a thorough inspection and cover everything they are supposed to.

There is a place at the top of the form for your NAR membership number. You might not have received one yet if you just joined NAR. If you don't have your number, bring proof that you joined NAR with you, such as the online receipt for your membership fee or a canceled check.

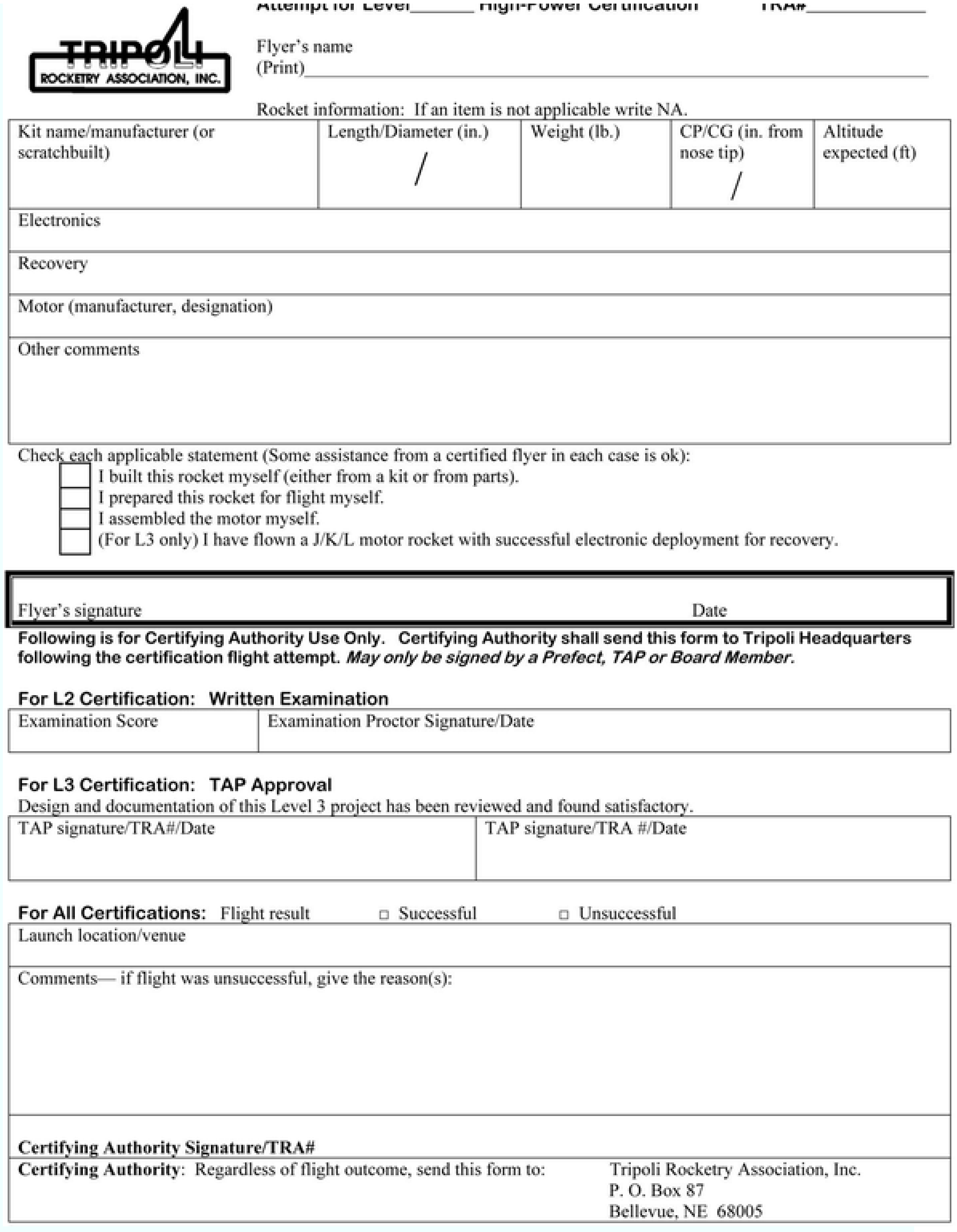
There are a couple of things you will no doubt notice as you read through the form, especially the second page. Some are part of the flight preparation, like making sure the nose cone is not too loose. Others don't apply to Callisto, but might apply to other rockets you could use for your Level 1 certification. For example, Callisto is not a cluster rocket, so all of the checks regarding clustered motors don't apply. It also doesn't fly high enough or fast enough for you to have to worry about vent holes to avoid premature separation. Other rockets in the book do; you will put vent holes in Deimos in Chapter 6, for example. Many of the items are checks to make sure you did a good job building the rocket.

Be sure you take the paperwork with you when you head out to the launch site.

Once your flight is complete, return the completed form to NAR at the address on the form. If you were certified at a big national launch, such as the NAR National Sport Launch (NSL) or the NAR Annual Meet (NARAM), the event organizers will probably keep the form and mail all of the certification paperwork to NAR in one bundle. You do get a temporary card on site. There is no fee. In a few weeks, NAR will send you an updated membership card with your new certification level.

TRA LEVEL 1 PAPERWORK

TRA will mail you a copy of the certification form with your membership packet, but you can also download the form online. If the link changes, do a web search for “tra high power certification.” The form is shown in Figure 4-3 for reference.



Attempt for Level______ High-Power Certification TRA#____________

TRIPOLI ROCKETRY ASSOCIATION, INC.

Flyer’s name
(Print)____

Rocket information: If an item is not applicable write NA.

Kit name/manufacturer (or scratchbuilt)	Length/Diameter (in.) /	Weight (lb.)	CP/CG (in. from nose tip) /	Altitude expected (ft)
Electronics				
Recovery				
Motor (manufacturer, designation)				
Other comments				

Check each applicable statement (Some assistance from a certified flyer in each case is ok):

☐ I built this rocket myself (either from a kit or from parts).
☐ I prepared this rocket for flight myself.
☐ I assembled the motor myself.
☐ (For L3 only) I have flown a J/K/L motor rocket with successful electronic deployment for recovery.

Flyer’s signature Date

Following is for Certifying Authority Use Only. Certifying Authority shall send this form to Tripoli Headquarters following the certification flight attempt. ***May only be signed by a Prefect, TAP or Board Member.***

For L2 Certification: Written Examination

Examination Score	Examination Proctor Signature/Date

For L3 Certification: TAP Approval

Design and documentation of this Level 3 project has been reviewed and found satisfactory.

TAP signature/TRA#/Date	TAP signature/TRA #/Date

For All Certifications: Flight result ☐ Successful ☐ Unsuccessful

Launch location/venue

Comments— if flight was unsuccessful, give the reason(s):

Certifying Authority Signature/TRA#

Certifying Authority: Regardless of flight outcome, send this form to:

Tripoli Rocketry Association, Inc.
P. O. Box 87
Bellevue, NE 68005

Figure 4-3. The TRA high-power certification form

TRA uses the same form for all three certification levels. By now you know that you can get all of the information for the top row from OpenRocket. The Electronics box is where you list trackers or altimeters used to deploy ejection systems. Leave it blank unless you added a tracker of some sort. In the Recovery box, enter “36-inch parachute.” After entering the motor details, there are some checkboxes where you confirm that you built and prepared the rocket yourself. Everything else is for the certifying official.

There is no fee for the Level 1 certification. Return the completed form to TRA at the address listed on the form. I scanned mine and emailed the file to *info@tripoli.org* (check before you send, in case the email has changed). That worked just fine. You will get an updated certification card in the mail with your new certification level. I was able to buy H and I motors, as well as a J motor for my Level 2 certification, by emailing a scan of the same completed form to the vendor.

The Importance of Checklists

If you’re a normal human being, the whole process of building and flying a high-power rocket is going to be pretty exciting. After a while some parts of the process will start to get routine, though, and you will gain some much-deserved confidence in your abilities. And guess what? That’s when you are going to make a mistake. You’re going to forget something.

That’s why you need a checklist. Checklists have a long history in aviation. I still remember my initial flying lessons at the Air Force Academy. One of the first things we got was a small notebook filled with checklists. We studied those checklists, memorizing them against the day when something bad or unexpected would happen—and it would, our instructor pilots made sure of that!

So, when we were finished memorizing the checklists, did we toss them in a drawer for periodic review? Nope. We took them with us to the flight line and strapped them to our legs. In many situations, we would still flip open the pages we knew so well and run through the checklists. Why? Because it made mistakes a lot less likely, and the Air Force didn't want to lose expensive airplanes or the pilots flying them. From pilots to surgeons to ambulance drivers, checklists have been proven time and again to reduce accidents. The biggest problem with a checklist is actually that the very people who need them the most think they are too smart or too experienced to need one. Repeated studies show they are wrong—all too often dead wrong.

Rocketry is no different. From small, low-powered rockets to massive interplanetary probes, checklists are a fully integrated part of every launch operation. Some are admittedly mental lists we run through for simple operations, but many are written checklists. That's one of the things you will be expected to have when you make your certification flights.

As you read through the rest of this chapter, there will be several checklists. I'll even suggest some alternatives. It's the way we keep ourselves safe when flying rockets.

The Level 1 Motor

You have some choices when it comes to buying a Level 1 motor. There are two large companies that sell motors for high-power rocketry, as well as a number of smaller ones. We're going to look at motors from the two large companies, including how you prepare them for flight and the advantages and disadvantages of each.

WARNING

It should be obvious, but don't unpack or handle motors or components near any open flame or heat source.

In broad brushstrokes, there are three fairly different kinds of motors you can use for your Level 1 certification flight. The first motor we will look at is the AeroTech H128W-M. It is the most involved to build, which can be good or bad, depending on your goals. The motor reload contains a bag of fuel pellets, called grains; a delay charge; black powder for an ejection charge; and various O-rings, washers, and a nozzle. I really get a kick out of assembling the motor and seeing how all of the parts fit together, but you may not.

The next motor we will look at is the Cesaroni H163-14A. In many ways, it's a prepackaged motor that you simply slide into a metal motor case before launch. There is much less to assemble, much less to go wrong, and cleanup is usually a little easier. These are very adaptable motors with some real advantages in terms of the number of motor casings you need to buy, but you may still end up disassembling and reassembling the motor.

The third motor is the AeroTech H135W-14A. This is a preassembled, disposable motor. You don't have to buy a separate, expensive motor case. On the other hand, the motor itself costs more per flight than either of the first two. The AeroTech disposable motor system is the easiest to get ready for flight. It can also save you money if you will only be doing a small number of flights with a particular size motor, but either of the reloadable systems will cost less if you make several flights with the same size motor.

There are a lot of other motors that will work great for your Level 1 flight. Any 29 mm H or I motor will be just fine in Callisto. The three motors just listed are merely a representative sample of the kinds of motors that are available. Be sure to run a simulation of any motor you consider, though. Motor weight varies quite a bit, and this can affect stability. These motors all have a total impulse near the lower end of the range for an H motor, right around 160 N-s, which will carry Callisto to around 2,000 feet. A large H or I motor can easily take the rocket over 3,000 feet. While that's very exciting, it's also likely to be out of sight—literally! Your certification flight isn't successful if you lose the rocket, so you might stick with the smaller H motors for the certification flight. If you do decide on a large H or I motor, I recommend adding a GPS or directional radio tracker.
See Chapter 10 for more information on trackers.

Buying a Motor

There are many vendors from which you can buy your Level 1 motor (see Appendix A for a list of vendors). Shop around a bit; motor prices and shipping prices vary. Look for certification specials, too. When I was getting my certifications, AeroTech was running a special promotion offering a free motor case for the Level 1 and 2 certification flights. This works well for you and the company; you get a case at no charge, and AeroTech gets you hooked on their motors. It was quite some time before I tried a Cesaroni motor. As I write this, both AeroTech and Cesaroni are running a similar special. Do a web search for “aerotech certification special” or “cti certification special” to see what is available.

The downside to ordering your motor is that you can only order one H or I motor, but you will need to pay the full hazardous materials (hazmat) shipping fee. The hazmat fee is per order, not per motor. This shipping fee is currently $28.50—more than the motor or the reload. You can ease the pain a bit if you also fly mid-power motors, since some of the highend G motors also require a hazmat fee. Ordering several mid-power motors reduces the hazmat cost per motor. It’s also not such a big deal for your Level 2 flight, since you can order several H and I motors at the same time. It’s quite a hit for that first Level 1 motor, though.

There are a couple of alternatives. Check with your local club. Many clubs have a member who sells motors and reloads. You might also find another member who is ordering motors; by making one combined order, each of you pays less of the total hazmat fee. You can also buy reloads at large national launches and many large local launches.

Of course, buying locally means you miss out on the experience of seeing your local carrier gingerly handing a package with large “explosive” labels, clearly glad to get whatever it is you’ve ordered out of their truck!

Building the AeroTech H128W-M

The AeroTech H128W-M is one of those motors that sits right on the boundary between G and H. Various references, all presumably based on thrust stand testing of the motor, list the total impulse for the motor at 178 N-s, 156 N-s, or 175 N-s. Anything with a total impulse of 160 N-s or less is a G motor, and anything greater than 160 N-s up to 320 N-s is an H motor, so different tests for this motor classify it as either a full G motor or a small H motor. Since it’s the letter on the package that counts, this is classed as an H motor, perfect for your certification flight.

AeroTech reloadable motors need two major components. One is the reload. This is the package in Figure 4-4. It contains the rocket fuel, delay charge, and so forth—all of the parts of the rocket motor that burn up or get thrown away after each flight. The other part is the motor hardware, shown at the bottom of Figure 4-4.

For this particular motor, the motor hardware is made up of three parts. The motor case is the black anodized aluminum tube with the printed label. There are two pieces that screw into the motor tube, called closures. The forward closure houses the ejection delay charge and the ejection charge. It is the irregular black anodized aluminum end on the right side of the motor in Figure 4-4. The aft closure holds the nozzle in place. It's the brass-colored part on the left of the motor assembly. Larger AeroTech motors use a fourth piece, another aluminum part called the forward seal disk, that provides a strong bulkhead at the forward end of the combustion chamber for the larger motors. The forward seal disk is a fiber disk in the smaller 29 mm motors like this one.

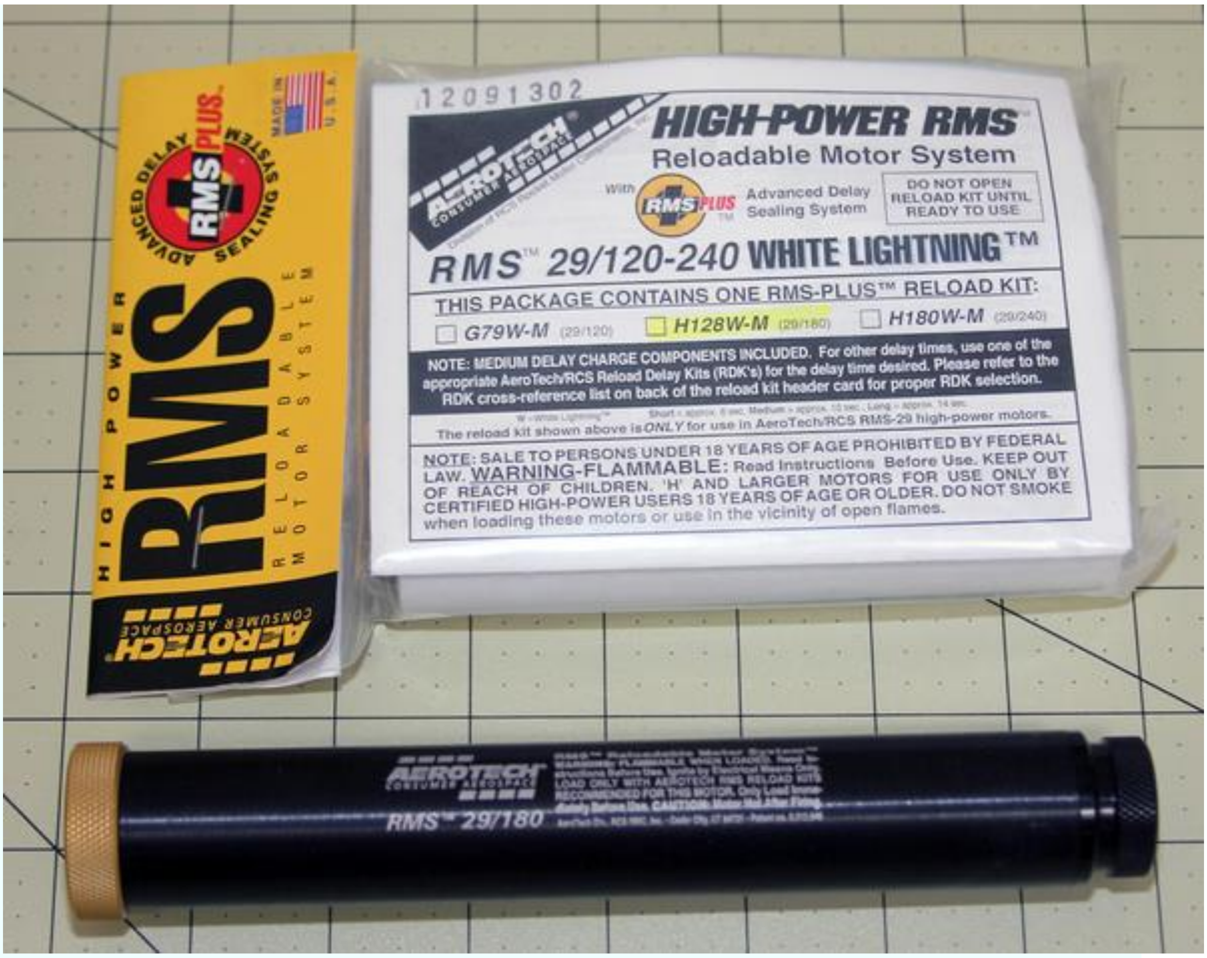

HIGH POWER RMS RELOADABLE MOTOR SYSTEM
AEROTECH CONSUMER AEROSPACE
ADVANCED DELAY SEALING SYSTEM RMS PLUS
MADE IN U.S.A.
12091302
HIGH-POWER RMS Reloadable Motor System
With RMS PLUS Advanced Delay Sealing System
DO NOT OPEN RELOAD KIT UNTIL READY TO USE
RMS 29/120-240 WHITE LIGHTNING™
THIS PACKAGE CONTAINS ONE RMS-PLUS™ RELOAD KIT:
☐ G79W-M (29/120) ☐ H128W-M (29/180) ☐ H180W-M (29/240)
NOTE: MEDIUM DELAY CHARGE COMPONENTS INCLUDED. For other delay times, use one of the appropriate AeroTech/RCS Reload Delay Kits (RDK's) for the delay time desired. Please refer to the RDK cross-reference list on back of the reload kit header card for proper RDK selection.
The reload kit shown above is ONLY for use in AeroTech/RCS RMS-29 high-power motors.
NOTE: SALE TO PERSONS UNDER 18 YEARS OF AGE PROHIBITED BY FEDERAL LAW. WARNING-FLAMMABLE: Read Instructions Before Use. KEEP OUT OF REACH OF CHILDREN. 'H' AND LARGER MOTORS FOR USE ONLY BY CERTIFIED HIGH-POWER USERS 18 YEARS OF AGE OR OLDER. DO NOT SMOKE when loading these motors or use in the vicinity of open flames.
AEROTECH CONSUMER AEROSPACE
RMS™ 29/180

Figure 4-4. An AeroTech reloadable motor consists of the reload, shown packaged on top, and the motor hardware, shown at the bottom.

We already looked at the meaning of the markings for the reload back in “Rocket Motor Labels”. H tells you the total impulse is greater than 160 N-s, but less than or equal to 320 N-s. The 128 is the average thrust in newtons, and the M at the end indicates the motor has a medium-delay ejection charge. From the manufacturer’s data sheet, available on the AeroTech website, we find that the actual delay is 10 seconds. You learned that the W indicates the fuel type (in this case, White Lightning). Let’s take a closer look at the different fuel types now.

AeroTech currently makes motors using seven fuel types, each with slightly different characteristics. Slow-burning fuels are great for high-altitude rockets, since they let the rocket travel slower though the thick atmosphere for a longer time, not wasting energy due to excessive drag. Fast-burning fuels are good for speed and weight, allowing a rocket to burst through the sound barrier or providing the lift needed for a heavy rocket. Other fuels provide colored flame or dense smoke for tracking. Table 4-1 reproduces the descriptions of the fuel characteristics from the AeroTech catalog, which you can find on their website under the Products tab; Figure 4-5 shows the fuel formulas in action.

Designation	Name	Description
W	White Lightning	A brilliant white flame, dense bright white exhaust an the hallmarks of this popular propellant. Easy to track White Lightning looks and sounds like actual soundin launch vehicles. Special effects professionals and aero specify the AeroTech White Lightning propellant to a simulation.
T	Blue Thunder	Produces a bright violet-blue flame with a minimum o These motors provide a higher level of thrust than Wh Black Jack motors of the same total impulse. Blue Th propellant for high lift-off acceleration.

Designation	**Name**	**Description**
J and FJ	Black Jack (J) and Black Max (FJ)	Provides the high visibility tracking of dense black ex to a distinctive lift off roar, Black Jack motors give yo acceleration and longer powered flight than White Lig Thunder motors of the same total impulse. Black Max higher acceleration than White Lightning Propellant.
R	Redline	Distinctly different from its propellant relatives, Redli visual and thrust characteristics for larger airframes ar oriented flyers. The proprietary AeroTech formulation with its signature vivid scarlet flame. Redline's burnin between that of White Lightning and Blue Thunder. P justice to the "laser-beam" intensity and color of Redl see it to appreciate it!
N	Warp-9	If you blink you'll miss it! Displaying a prominent ye studded with "mach diamonds," Warp-9 is AeroTech' propellant. Originally developed for Orbital's Pegasus 9 is perfect when you need the highest thrust possible size. Alternatively, when used in an "endburning" gra Warp-9 delivers unique thrust curve profiles such as t new G69N, I49N, I59WN, and L339N reloads.
G	Mojave Green	Mojave Green is AeroTech's newest propellant design use and RMS reloadable motors. Named for the infam rattlesnake with two types of venom that roams the de produces a vivid emerald green flame with brilliant ar diamonds" and a moderate amount of smoke. Mojave density and specific impulse delivers a higher total im size than any other AeroTech propellant. Motor burn t Green are similar to those produced by Redline.

Table 4-1. AeroTech fuel types

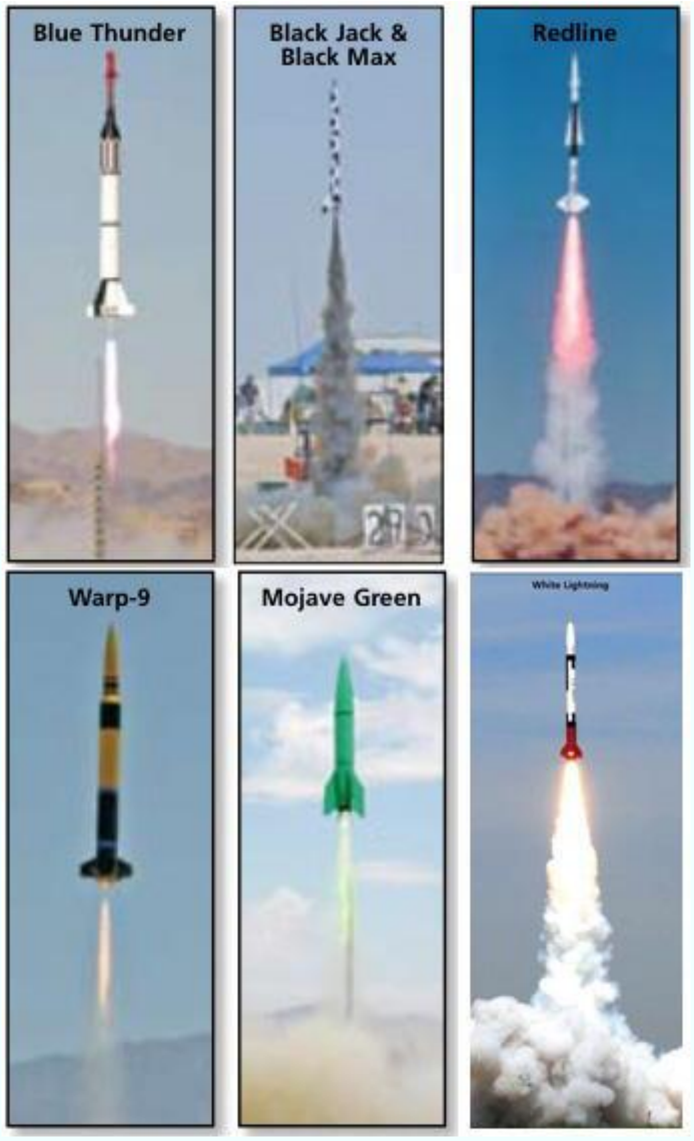


Figure 4-5. Visuals of the various AeroTech fuel formulas.

Motor casings can be used for a variety of motor reloads. The current AeroTech catalog lists four different reloads that fit this motor casing. One, for example, is the G75J-M. Since the motor hardware can take multiple reloads, and the reloads can have various powers, it doesn't make sense to label the motor casings using a letter. This motor casing is called the AeroTech 29/180, indicating that the motor case is 29 mm in diameter, so it will fit into the 29 mm motor tube in Callisto, and can handle up to 180 N-s of total impulse. The actual reloads listed for this motor hardware in the current AeroTech catalog range from 155 N-s to 175 N-s.

When you start looking for motor cases for AeroTech motors, you'll find that a lot of them are listed as RMS motors. The RMS in the motor designation reveals an interesting partnership, although one that is coming to an end. Until recently, AeroTech didn’t actually make most of its motor hardware; it concentrated on the reloads. A company called Rouse-Tech made the hardware, which it labeled as Monster Motor products. As with many high-power rocket companies, though, Rouse-Tech was primarily driven by a single individual, Tom Rouse. After 10 years of making a very large fraction of the motor casings used in high-power rockets, Tom has moved on. AeroTech has bought the company and its remaining stock. Motors made by AeroTech sport the black and bronze color scheme seen in Figure 4-4, while motors made by Rouse-Tech are blue and aluminum, like those in Figure 4-6. As the Rouse-Tech stock is depleted, AeroTech plans to replace the motors with its black and bronze color scheme. The parts can be mixed and matched.

Whoever makes them, the motor tube comes in several lengths for each diameter of motor. The forward closure, aft closure, and forward seal disk are the same for all of the motors with the same diameter. This can save you a lot of money. You can buy, say, the 29/180 motor case shown in Figure 4-4 with the forward and aft closures, then buy just the motor case and forward seal disk for the 29/360. The forward and aft seals from the 29/180 will work just fine with the 29/360.

Figure 4-6 shows the complete line of 29 mm motor hardware from Rouse-Tech. The motor cases are the 29/60, 29/100, 29/120, 29/180, 29/240, and 29/360. The two larger motor casings all need a forward seal disk; the smaller motors use a fiber one, as you will see when we assemble the H128W-M motor. The aft closure for RMS motors is metallic aluminum, with an aluminum forward seal disk. The 29 mm motor line has two styles of forward closure. The one on the far right is the same as the black anodized aluminum closure from Figure 4-4; it is set up for an ejection charge. The next one to the left is called a sealed forward closure. It doesn’t have an ejection charge. You will see this style of closure again in Chapter 8, when we modify a rocket to use dual deployment.

Larger AeroTech motor cases also have another style of forward closure called a tapped forward closure, which allow you to screw something into them. In Chapter 13, we’ll use a tapped forward closure to attach the shock cord, giving a firm attachment point. Figure 4-7 shows these three closure styles for 38 mm motors.

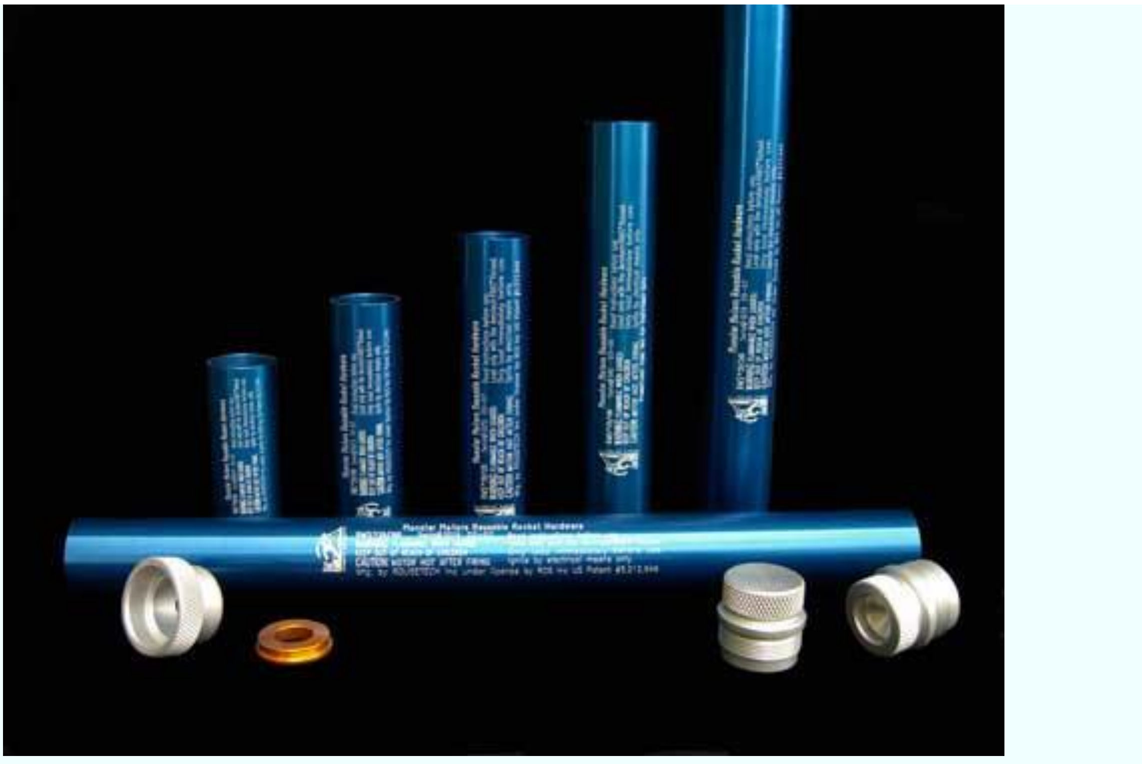


Figure 4-6. The complete line of hardware from Rouse-Tech for AeroTech 29 mm motor reloads.

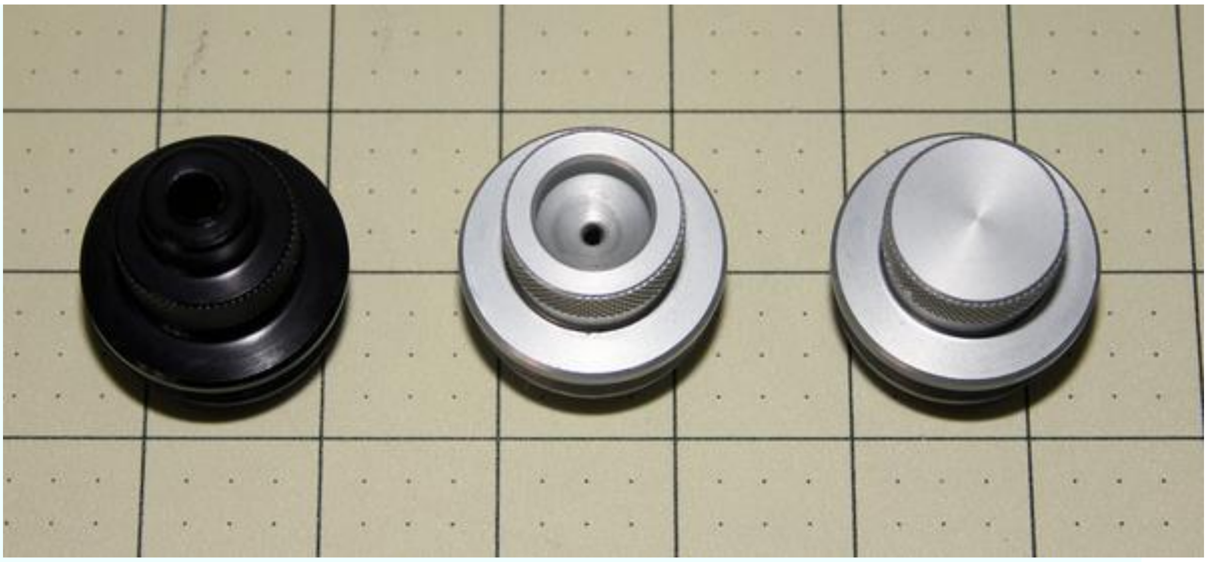


Figure 4-7. There are three closure styles for most AeroTech motor sizes. From left to right are the tapped forward closure, a closure used with ejection charges, and a sealed forward closure.

AeroTech reloads and Rouse-Tech motor hardware are available in other diameters, including 38 mm, 54 mm, 75 mm, and 98 mm. AeroTech also makes some low- and mid-power reloadable motors with motor cases that are 18 mm and 24 mm in diameter. These fit nicely into low-power rockets, replacing the single-use black powder motors normally used in the low-power rockets with more powerful reloadable motors.

Breaking the package open and unscrewing the parts of the motor base, we get the array of parts shown in Figure 4-8.

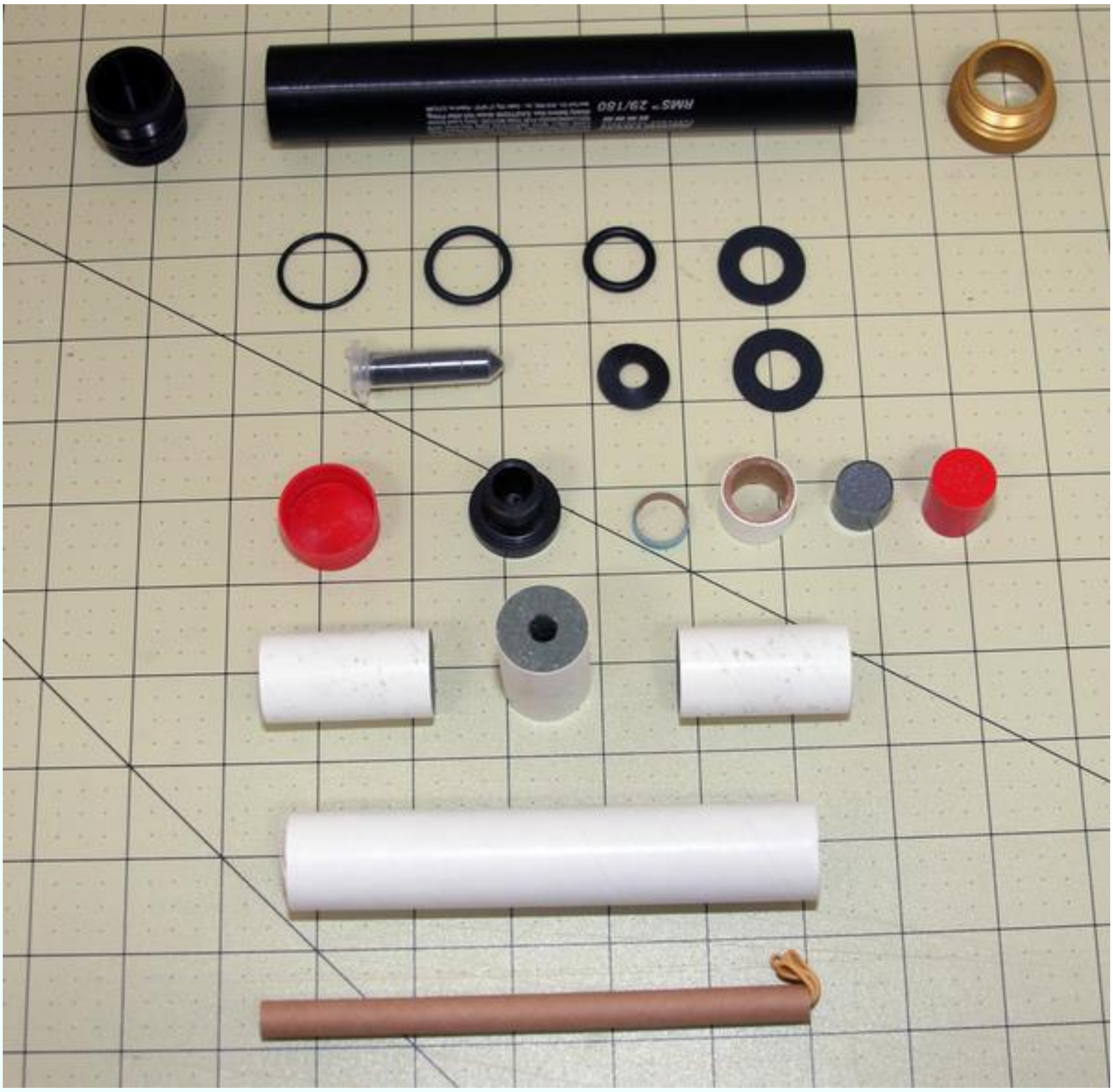


Figure 4-8. The parts for the motor hardware and H128W-M motor reload.

The motor hardware is in the top row, disassembled to clearly show the forward and aft closures.

The next two rows have the various O-rings and seal disks, plus the capsule of black powder used for the ejection charge. The next row has the two red plastic caps used to seal the forward and aft ends of the completed rocket motor, the nozzle, and parts for the ejection delay charge.

The three fuel grains are next. High-power rocket fuel in larger motors is usually set up in a series of chunks called grains. These grains don't always fit together snugly. In some larger motors there are even O-rings inserted between the grains to deliberately keep them apart. This is done to give more even thrust as the rocket motor burns through its fuel. This configuration is called a *Bates grain*, and it's a topic we'll look at in detail in Chapter 11. These three grains contain the ammonium perchlorate rocket fuel embedded in a soft epoxy resin that keeps the particles evenly mixed.

The bottom two components are the motor liner, which protects the motor case from the burning fuel, and the igniter.

The Many Names for an Igniter

The igniter for a rocket motor is an electronic device that heats a pellet of flammable material to start the motor. There are a lot of styles of igniters, depending on the intended use and the type of rocket motor they will light. They are not always called igniters, though.

You see, in the United States, there has been an ongoing conversation between the high-power rocketry community and the Bureau of Alcohol, Tobacco, and Firearms (the ATF). The ATF has the unenviable job of trying to protect us from the occasional maniac who would use various weapons, including explosives, to cause harm. Many of the components of both low- and high-power rocket systems can, unfortunately, be repurposed for nefarious uses. The ATF is constantly trying to balance the legitimate uses of the rocketry community with protecting the public. Occasionally this results in some rather humorous policies.

You see, *igniter* has become a bit of a dirty word. Igniters are used to, well, ignite things, and that makes some people understandably nervous. In several encounters with the ATF, members of the rocketry community have found that if they simply call the igniter something else, it helps the ATF approve our purchasing, ownership, and use of the devices we use to start our rocket motors. As a result, some companies now refer to igniters as starters, and others call them lighters.

I’ll use the term igniter in this book because the terminology question is still not completely resolved, but don’t be surprised if you go to buy a spare igniter and only find the company selling starters or lighters. A rose by any other name is still a rose, and the thing we start the motor with is still an igniter.

There are several O-rings and fiber disks in the reload kit. These come in various sizes, and it is really important that you get the right size O-ring and disk in the right place. If you don’t, your rocket motor could CATO, blowing up or, more likely, burning through the motor liner or blowing past the forward closure to damage the motor hardware or rocket. AeroTech includes a sheet of paper with images of the various disks and O-rings printed at actual size. I find it handy to lay the disks and O-rings out on the paper so it is crystal clear that when I reach for the 1” x 1/16” aft O-ring, that’s the one I really pick up. I suggest you lay this piece of paper out and place all of the O-rings and disks on it.

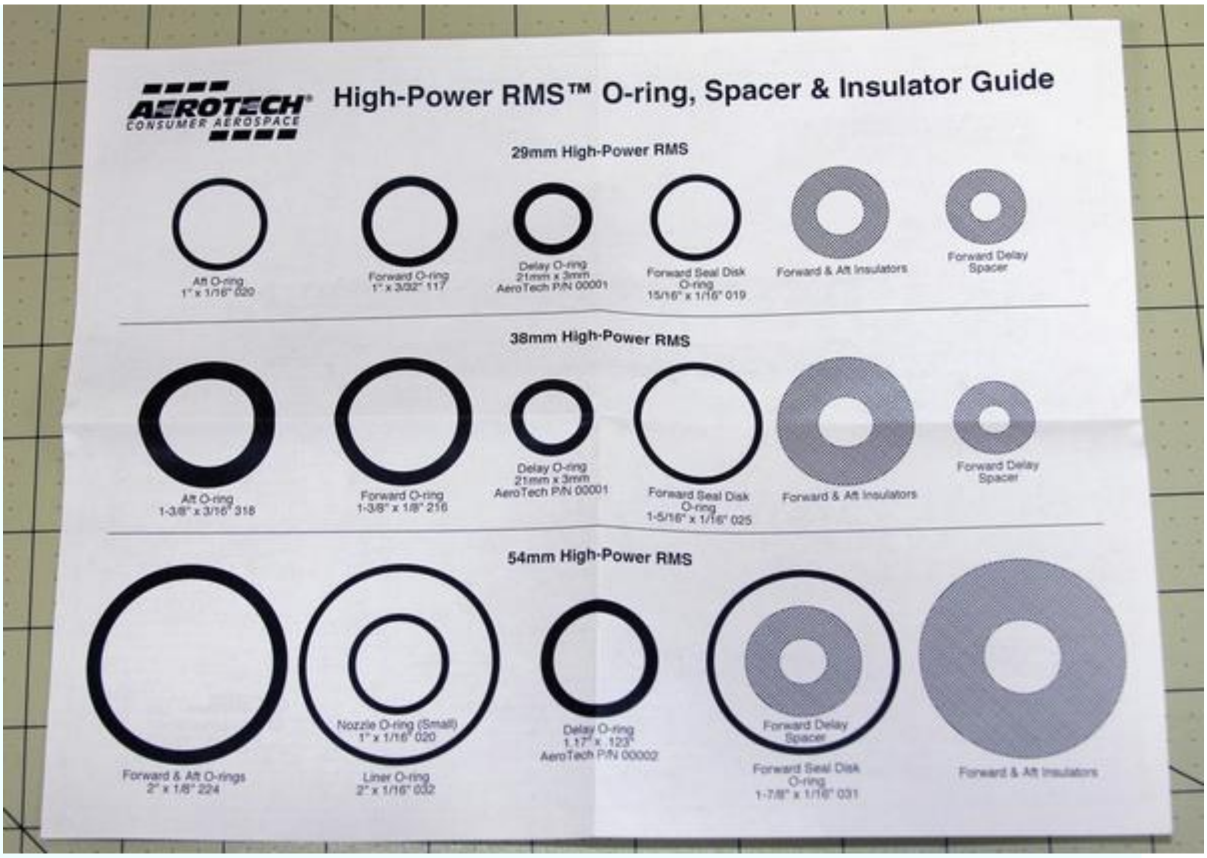

AEROTECH CONSUMER AEROSPACE
High-Power RMS™ O-ring, Spacer & Insulator Guide
29mm High-Power RMS
Aft O-ring 1" x 1/16" 020
Forward O-ring 1" x 3/32" 117
Delay O-ring 21mm x 3mm AeroTech P/N 00001
Forward Seal Disk O-ring 15/16" x 1/16" 019
Forward & Aft Insulators
Forward Delay Spacer
38mm High-Power RMS
Aft O-ring 1-3/8" x 3/16" 318
Forward O-ring 1-3/8" x 1/8" 216
Delay O-ring 21mm x 3mm AeroTech P/N 00001
Forward Seal Disk O-ring 1-5/16" x 1/16" 025
Forward & Aft Insulators
Forward Delay Spacer
54mm High-Power RMS
Forward & Aft O-rings 2" x 1/8" 224
Nozzle O-ring (Small) 1" x 1/16" 020
Liner O-ring 2" x 1/16" 032
Delay O-ring 1.17" x .123" AeroTech P/N 00002
Forward Delay Spacer
Forward Seal Disk O-ring 1-7/8" x 1/16" 031
Forward & Aft Insulators

Figure 4-9. Lay the O-rings and disks on the provided guide to make it clear which part is which.

Start the assembly by rubbing the O-rings with a grease lubricant. You can use a specialized O-ring grease like the one shown in Figure 4-10, or pretty much any other kind of grease. AeroTech specifically mentions that even common petroleum jelly is fine. Rub enough on so each of the O-rings is shiny, but not so much that they feel greasy. Make sure there is no hair, sand, or other grit on the O-rings.

WARNING

Do not apply grease to the various disks.

With the O-rings greased, the next step is to assemble the smoke delay charge. You will need the delay O-ring (the small, thick one), the small, thick cardboard delay insulator, the thinner blue aft delay spacer, and the delay element. These parts are shown in Figure 4-11.

Figure 4-10. Apply a light coat of grease to the three O-rings.

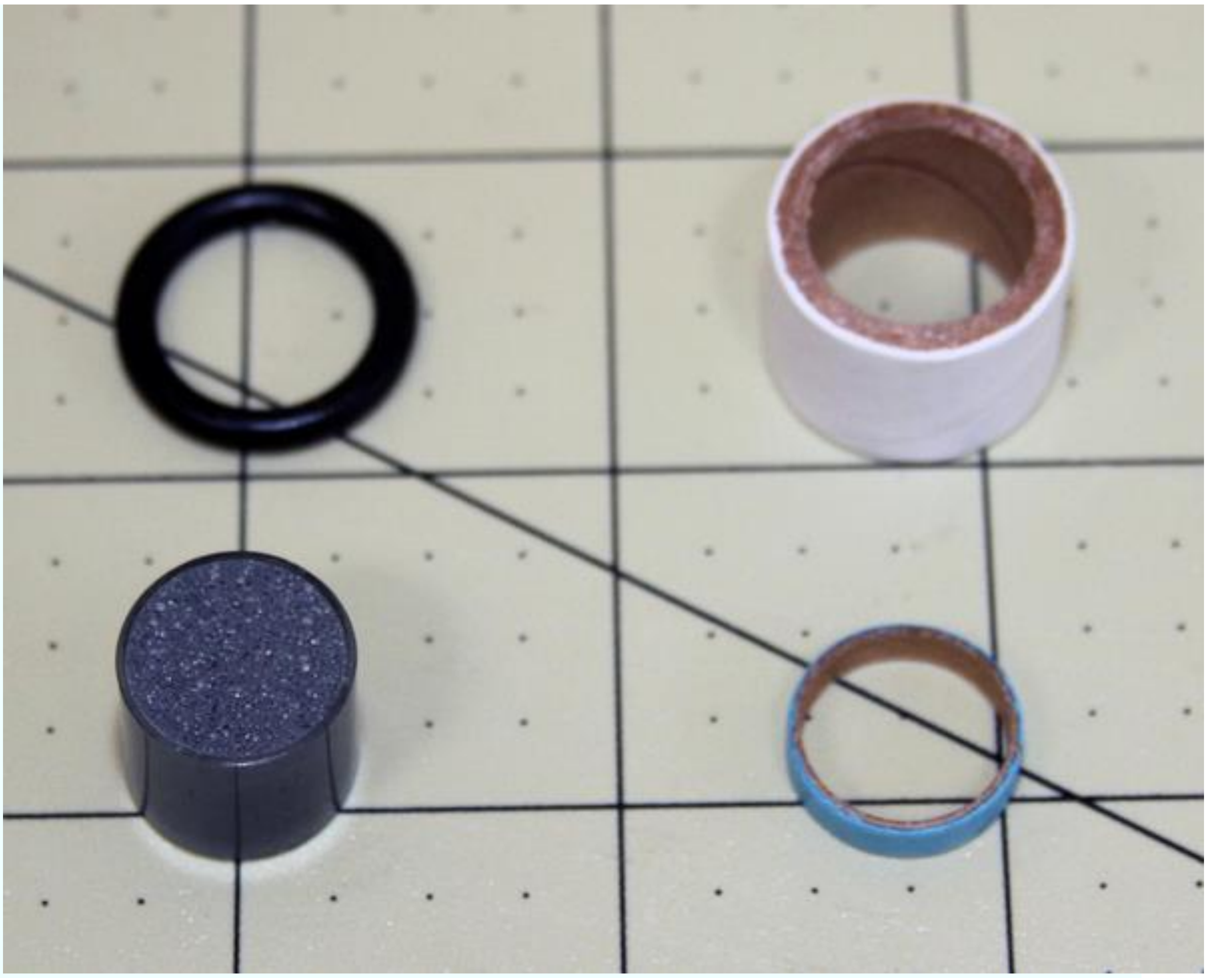


Figure 4-11. The delay section is made up of, from top to bottom and left to right, the delay O-ring, delay insulator, delay element, and delay spacer.

The delay element is the part that burns while the rocket coasts to apogee after burning all of the rocket fuel. It actually burns while the rocket fuel is burning, too, but it is swamped by the effect of the rocket fuel. It comes in three sizes. The H128W-M motor ships with the middle size, which burns for 10 seconds. There is a larger size that burns for 14 seconds, and a smaller one that burns for 6 seconds. You can order the alternative delay elements separately for rockets that need the 6- or 14-second delay times. These are called delay kits, and they come in specific sizes for the various reloads. The size of the delay spacer changes to accommodate the various sized delay charges.

Start the assembly by dragging your thumbnail around the inner corner on the delay insulator. This smooths out any protruding edge, and is called *chamfering* (see Figure 4-12).

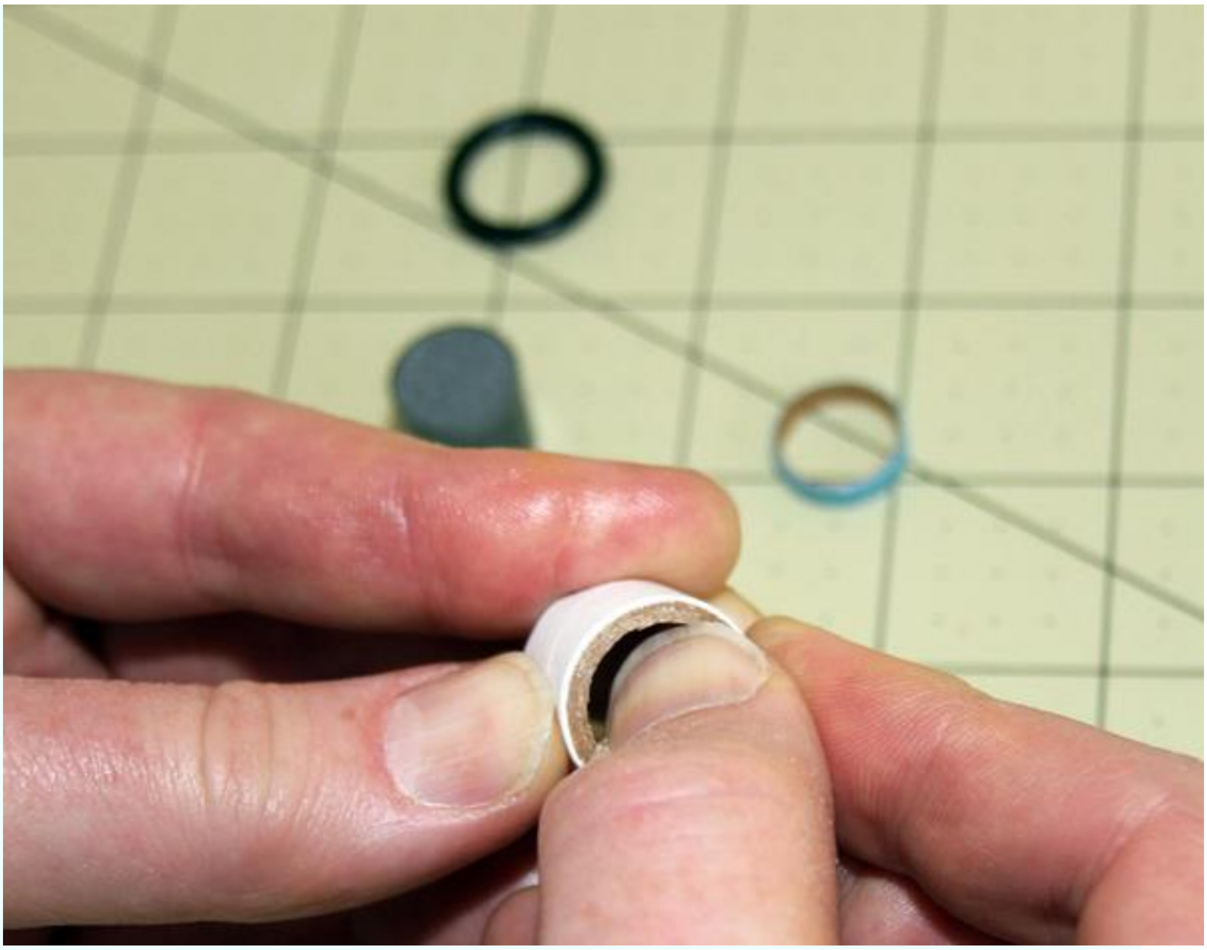


Figure 4-12. Chamfer the inner edge of the delay insulator so the delay charge slides in smoothly.

Insert the delay element, followed by the delay element spacer (see Figure 4-13). Push the spacer in until it is flush with the edge of the delay insulator. The delay element will stick out the other end a bit; this is normal.

Turn the assembly over and slide the delay O-ring over the protruding part of the delay element (see Figure 4-14).

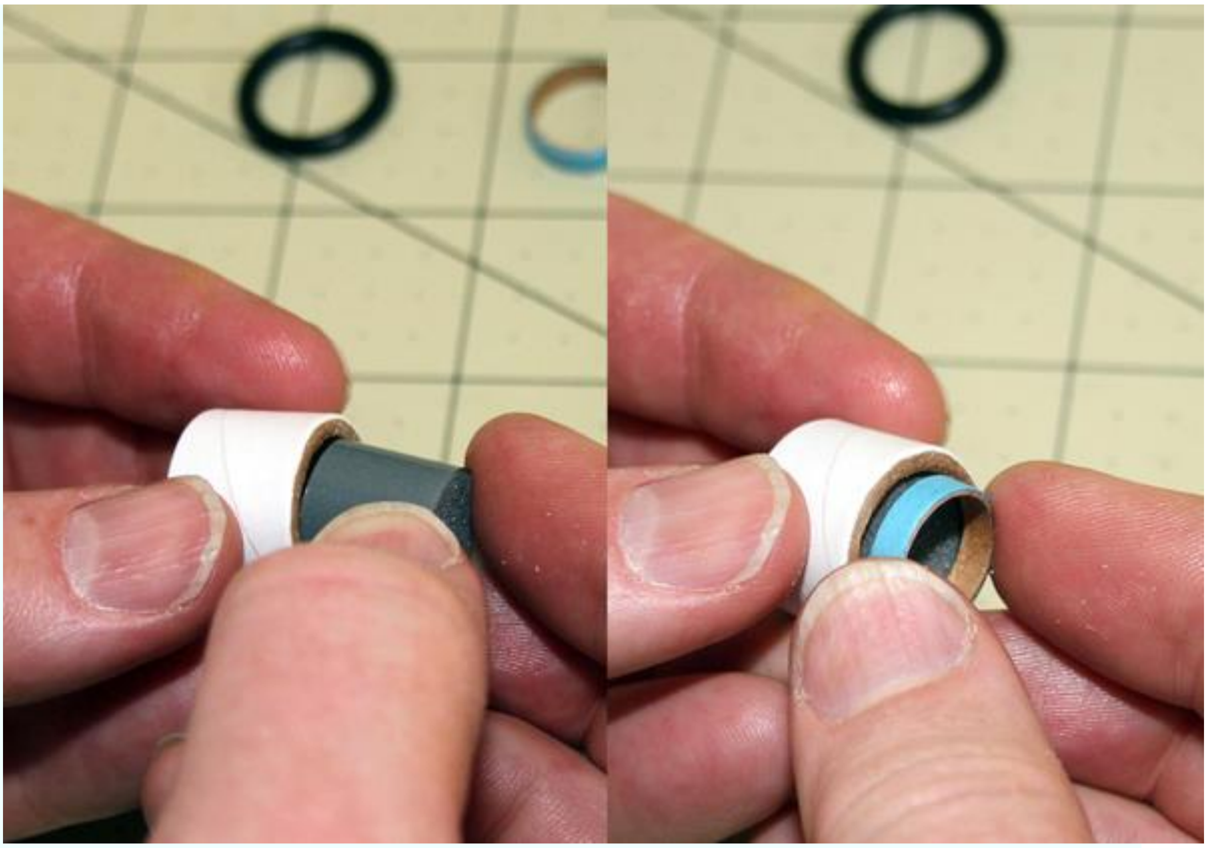


Figure 4-13. Insert the delay element and spacer.

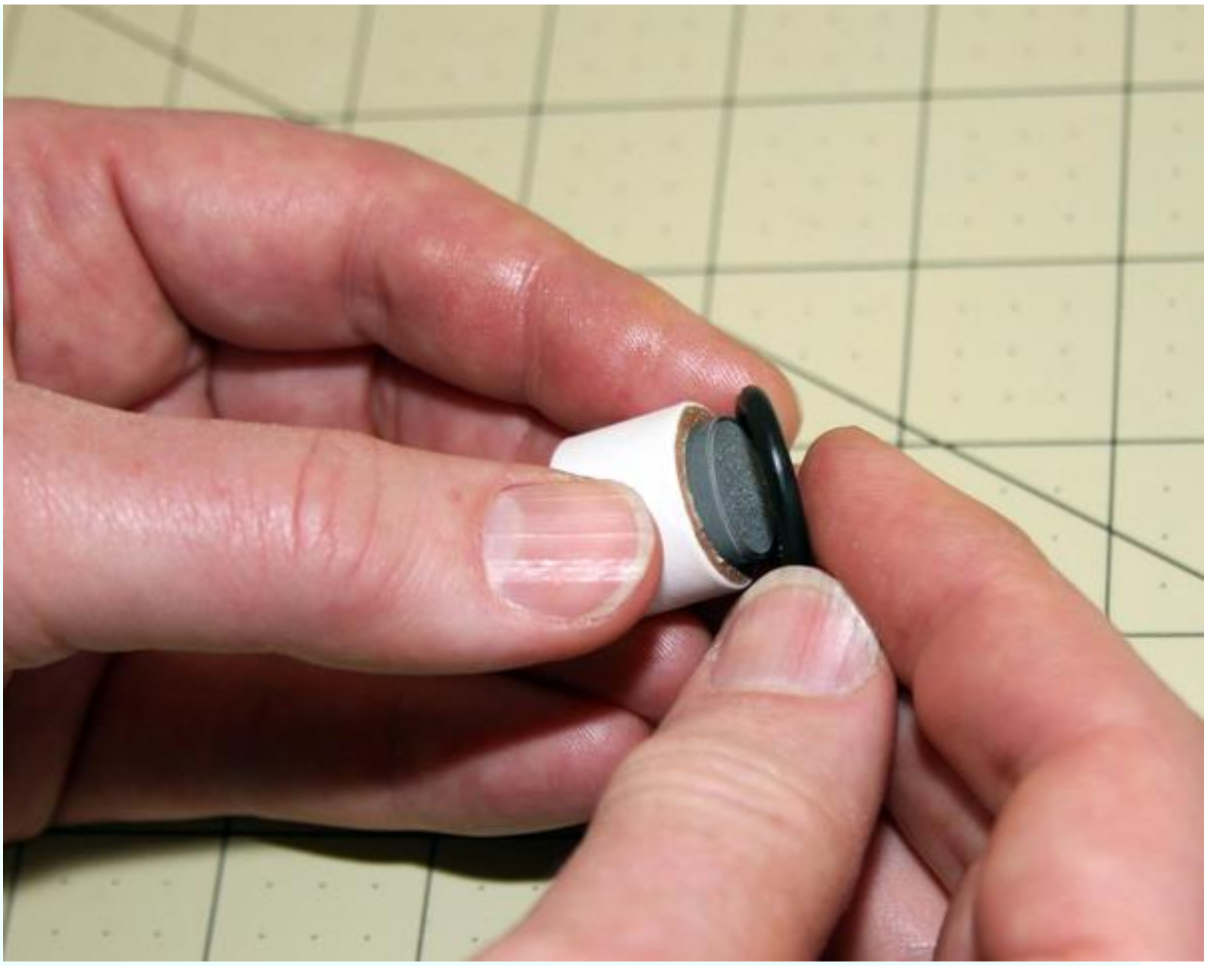


Figure 4-14. Install the delay O-ring.

Insert the forward closure delay spacer into the forward closure (see Figure 4-15). Apply a light film of grease to the inside walls of the forward closure, but don’t get any on the spacer. The grease helps the delay assembly to slide into place, and also makes cleanup a little easier after the motor is used. Push the delay assembly into place. The O-ring forms a tight fit, so you will have to push hard, but don’t use tools to force the assembly into place. Set the completed forward closure and delay element aside.

Test fit the motor liner in the motor case. I’ve occasionally found a motor liner that was way too tight for the case. If that happens, peel off the outer layer of paper so the motor liner slips into the case.

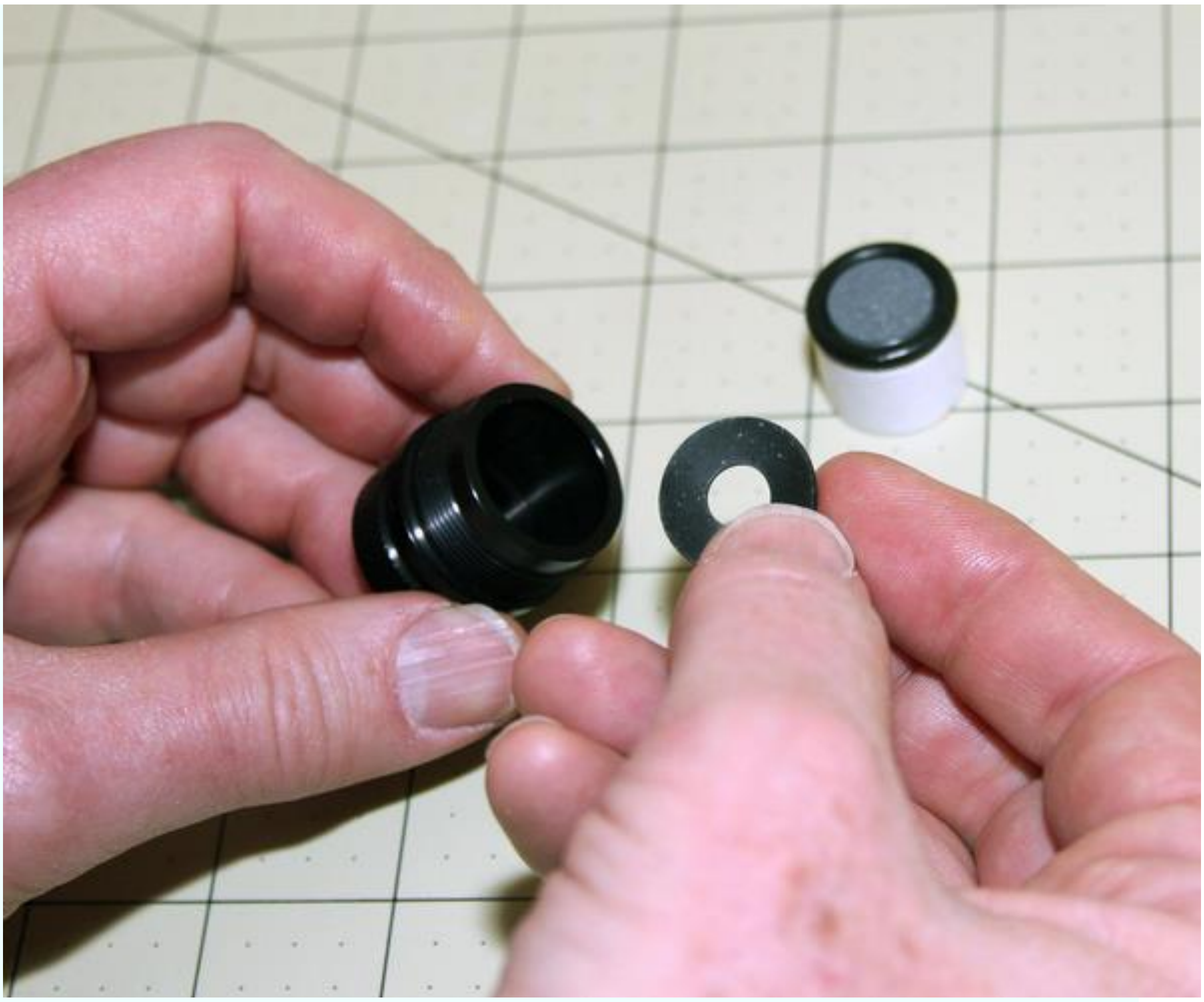


Figure 4-15. Insert the forward spacer, apply a light coat of grease to the walls of the forward closure, and slide the delay assembly into the forward closure, O-ring first.

There are three fuel grains in the H128W reload. Slide these into the motor liner (see Figure 4-16). They will slip out easily, and you don’t want the explosives dropping out and bouncing around your work area. They are not going to blow up or anything, but you might dent or crack the fuel grain. That could lead to a motor CATO when you try to launch the rocket. Keeping this in mind, you either need to balance the tube or put a finger over the lower end so the fuel grains don’t drop out.

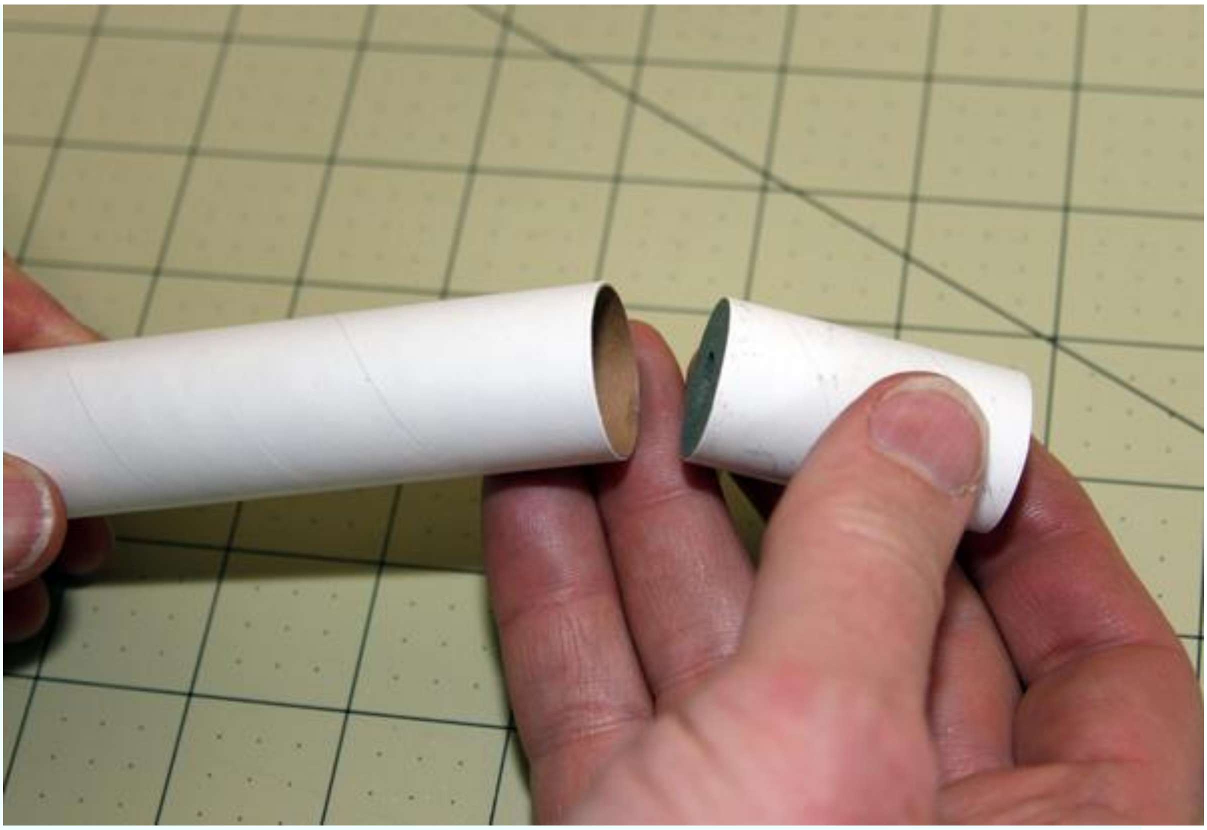


Figure 4-16. Slide the three fuel grains into the motor liner.

Coat the outside of the motor liner with grease (see Figure 4-17). This helps a lot when the time comes for cleaning up. Don’t get any grease on the fuel grains, though.

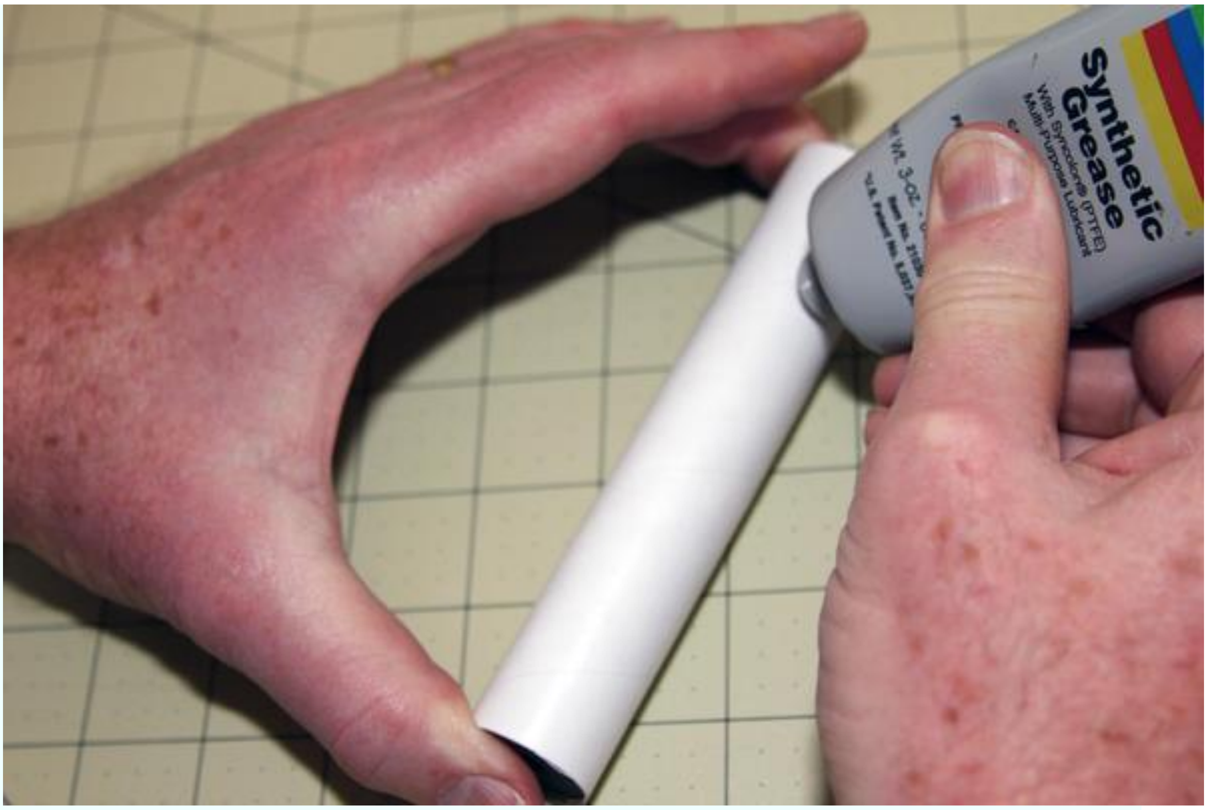


Figure 4-17. Coat the outside of the motor liner with grease.

Slide the motor liner with the fuel grains about halfway into the motor case (see Figure 4-18). While it’s not difficult, you need to exercise some care and precision here. The fuel grains can slide out of the motor liner, and the motor liner is coated in slippery grease that you don’t want to get on the fuel grains. Take your time and be careful. Wipe away any excess grease as you slide the assembly into place.

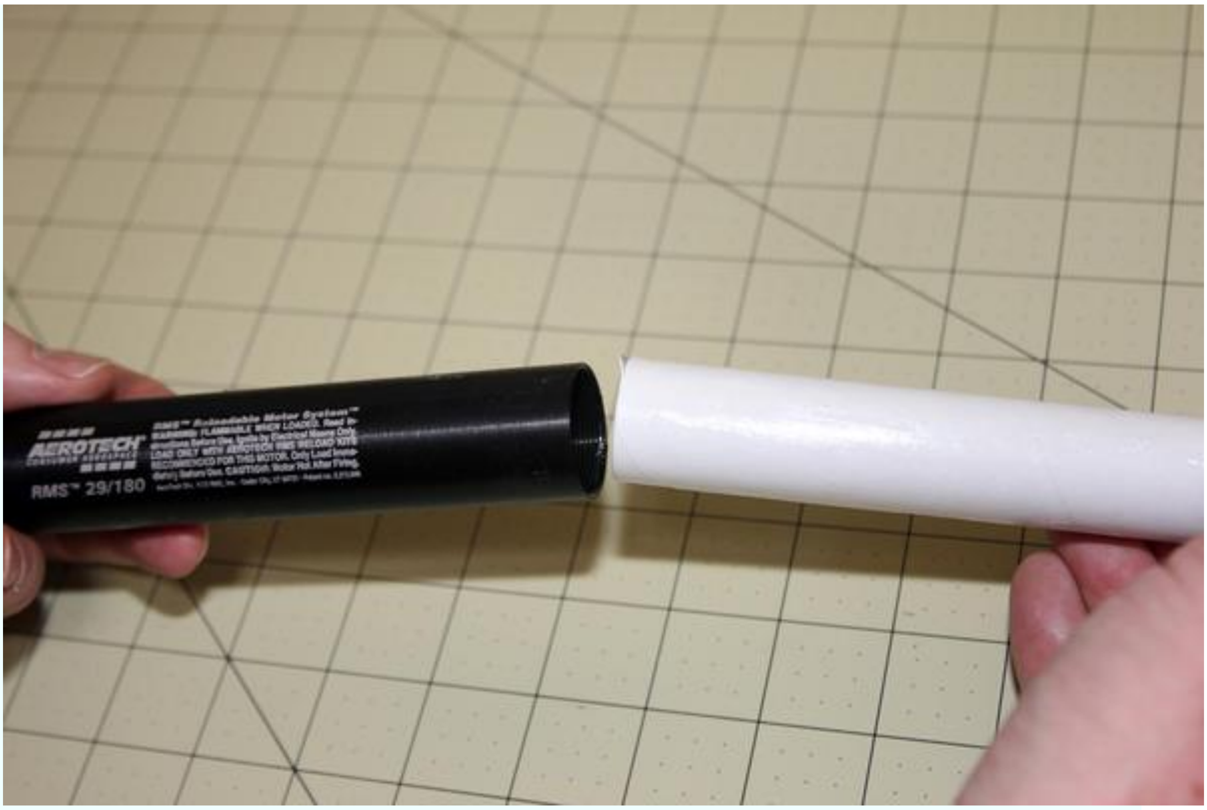


Figure 4-18. Slide the motor liner and fuel grains halfway into the motor case.

There are two identical insulators in the reload package. Slide one into the case, pushing it up against the motor liner (see Figure 4-19).

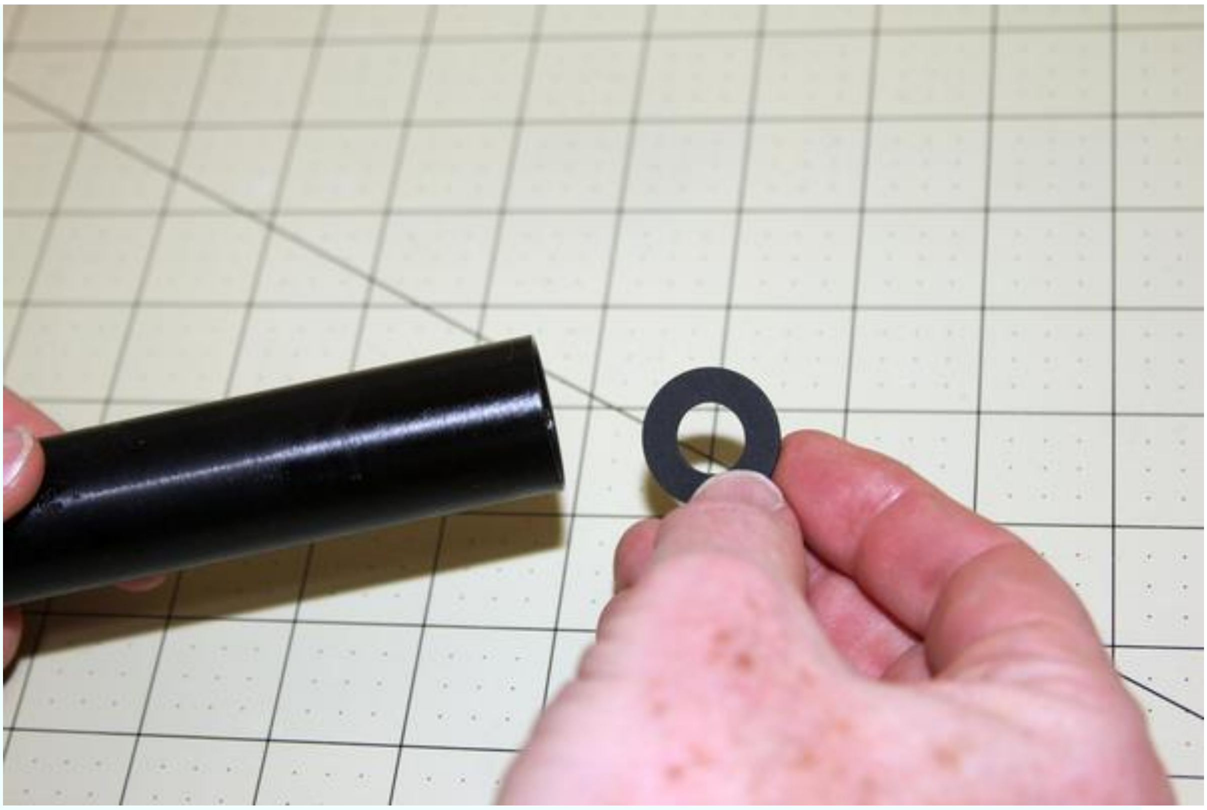


Figure 4-19. Slide the forward insulator into place.

There are two O-rings left. One of them is a little thicker than the other. That’s the forward O-ring. Place it against the forward seal disk (see Figure 4-20).

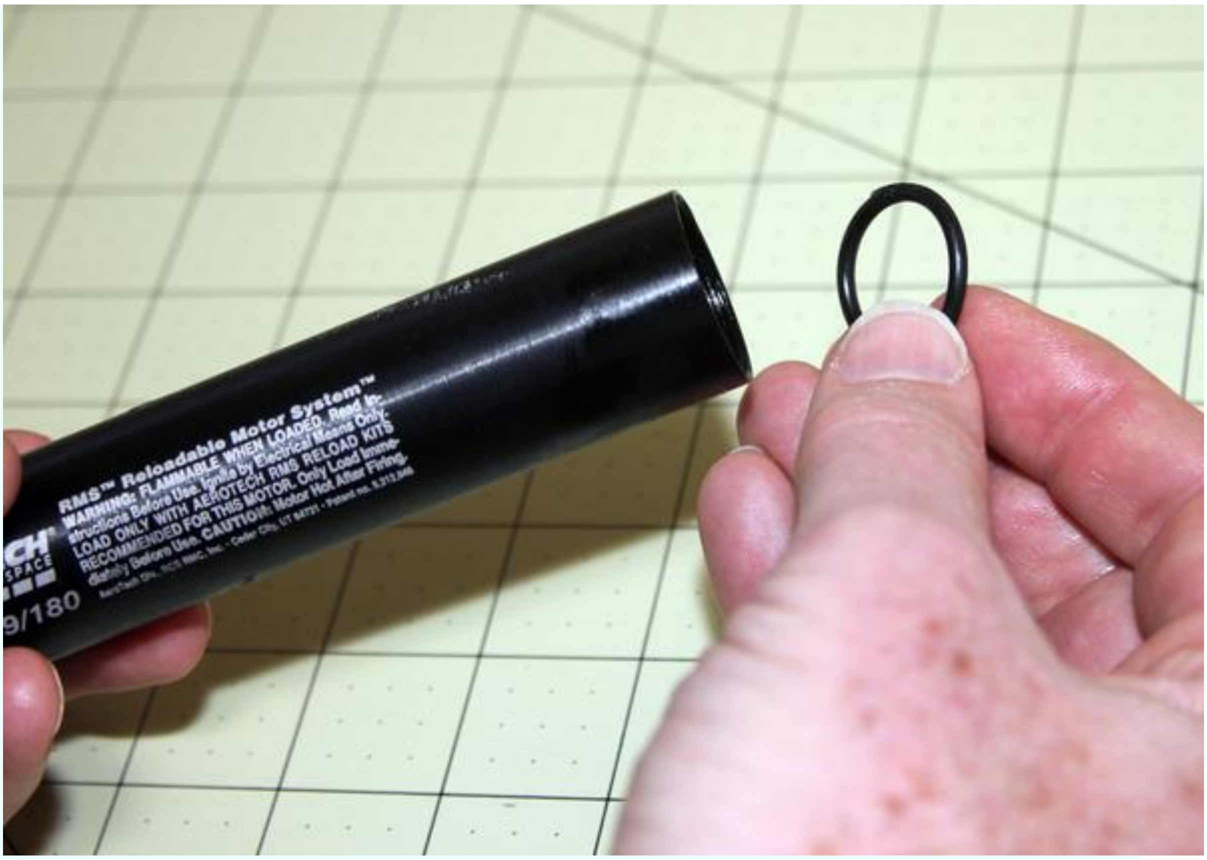

CH
SPACE
9/180
RMS™ Reloadable Motor System™
WARNING: FLAMMABLE WHEN LOADED. Read In-
structions Before Use. Ignite by Electrical Means Only.
LOAD ONLY WITH AEROTECH RMS RELOAD KITS
RECOMMENDED FOR THIS MOTOR. Only Load Imme-
diately Before Use. CAUTION: Motor Hot After Firing.

Figure 4-20. Insert the thicker O-ring; this is the forward O-ring.

There should be a little grease on the threads from inserting the greased motor liner. If not, add a small amount to the threads on the forward closure, and then screw it into place over the forward insulator and O-ring (see Figure 4-21). It just needs to be finger tight. Don’t use tools or get carried away trying to prove how strong you are.

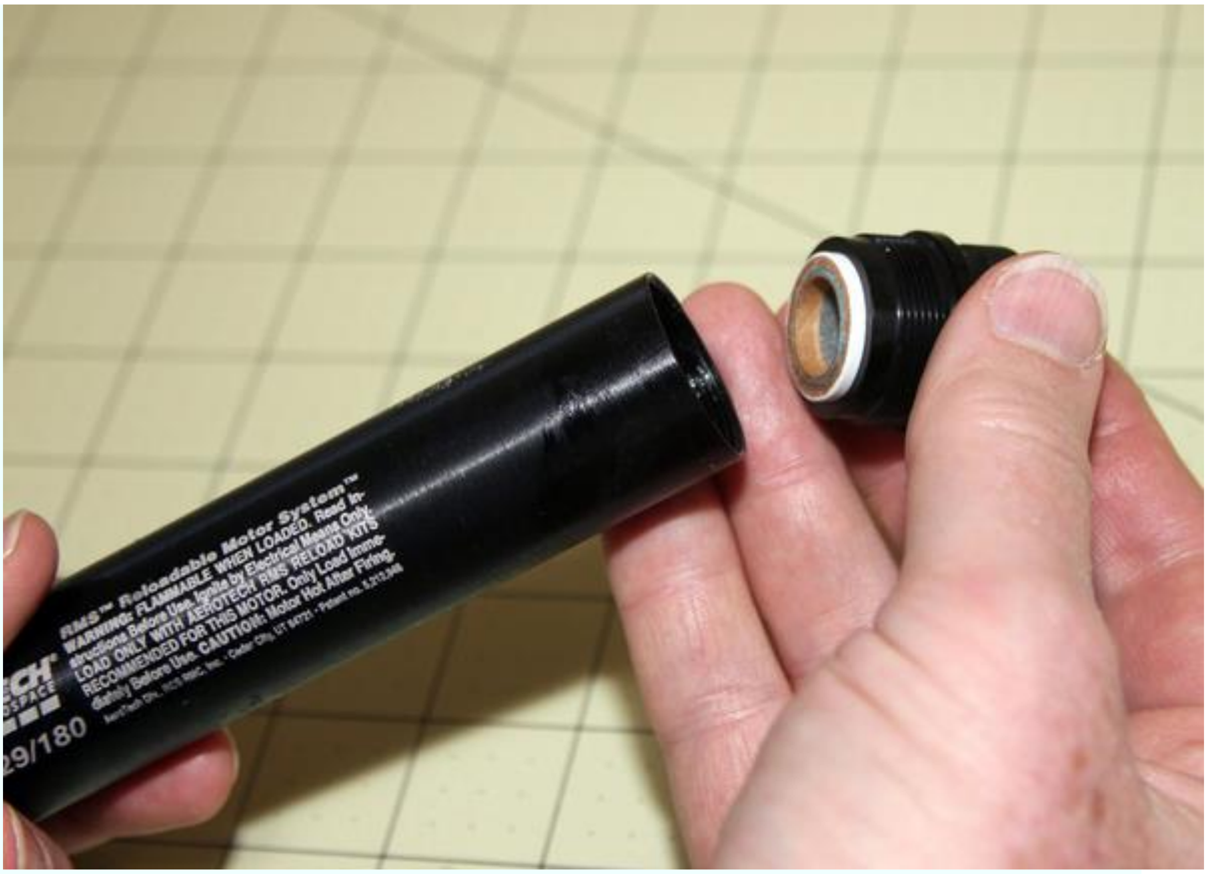

ECH
SPACE
29/180
RMS™ Reloadable Motor System™
WARNING: FLAMMABLE WHEN LOADED. Read In-
structions Before Use. Ignite by Electrical Means Only.
LOAD ONLY WITH AEROTECH RMS RELOAD KITS
RECOMMENDED FOR THIS MOTOR. Only Load Imme-
diately Before Use. CAUTION: Motor Hot After Firing.
AeroTech Div., RCS RMC, Inc. · Cedar City, UT 84721 · Patent no. 5,212,946

Figure 4-21. Grease the threads if they need it, then screw the forward seal into place.

The nozzle is an odd-shaped plastic part. Take a look down the throat of the nozzle. It might actually be closed, as shown in Figure 4-22. If so, use a pencil or other soft, conical shape to poke through the flash.

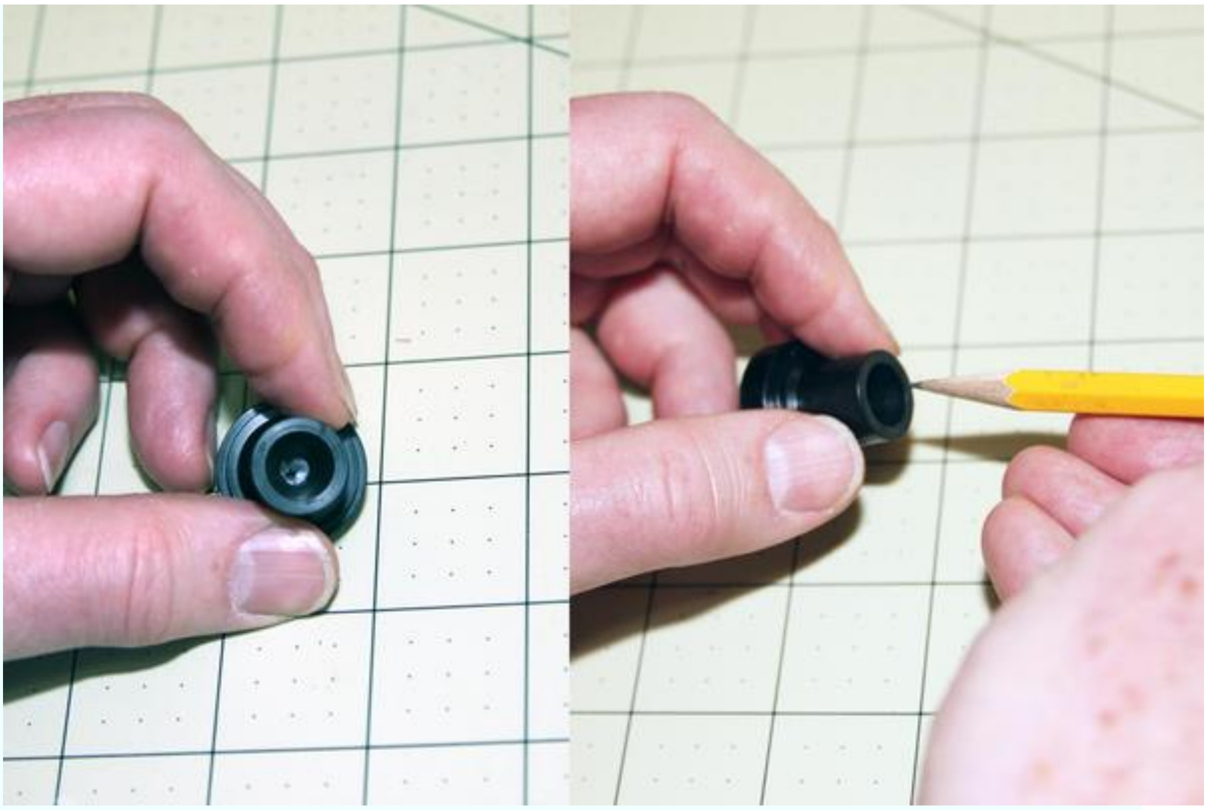


Figure 4-22. Make sure the nozzle is open. Use a pencil to poke through any plastic blocking the nozzle throat.

Insert the aft components, starting with the aft insulator. This disk is identical to the one that you inserted at the forward end. Next comes the nozzle, large end first. Follow this with the remaining O-ring (see Figure 4-23).

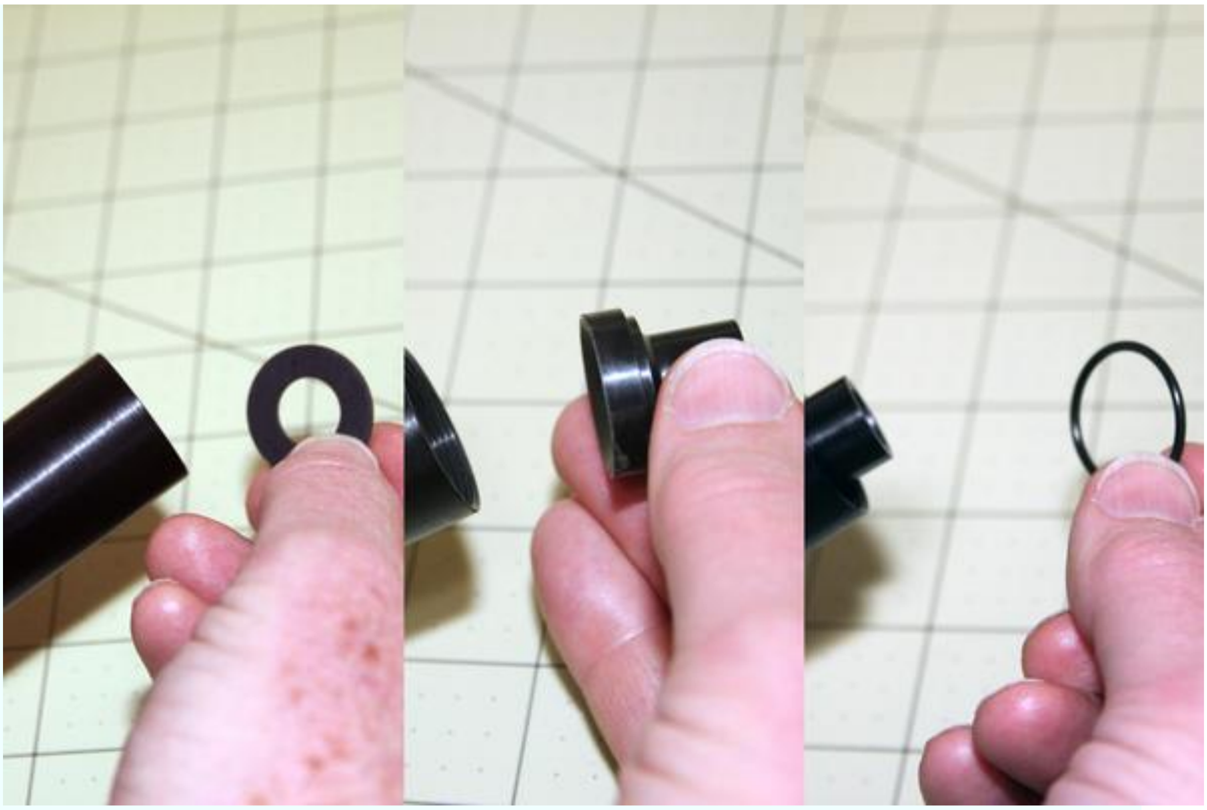


Figure 4-23. Insert the aft insulator, the nozzle, and the aft O-ring.

Apply a little grease to the threads of the aft seal if they are dry, then screw the aft seal into place (see Figure 4-24). You'll be seating and compressing O-rings as the seal gets close to the motor case. It's normal to feel some resistance for the last 1/16" or so. Again, don't use tools, but don't stop as soon as the resistance changes, either.

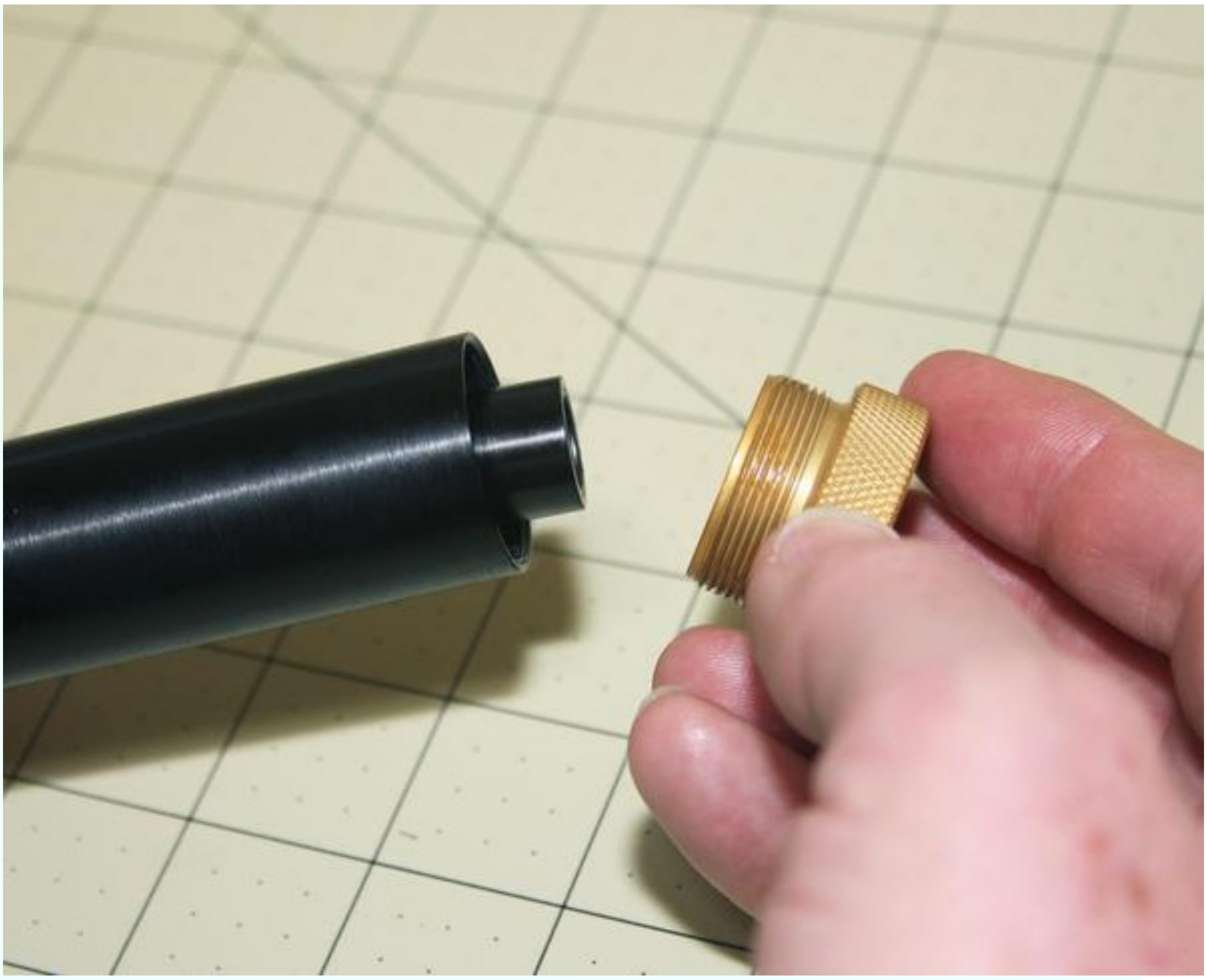


Figure 4-24. Screw the aft seal into place.

With the motor assembled, you might be a little startled when you tip it back and forth. The fuel grains will rattle around slightly. That’s actually normal. The grains need to burn from the ends, not just the central hole, so there is a small amount of space left between the grains. Larger motors even have O-rings that get inserted between the grains to make sure the space is even.

Wipe away any excess grease on the outside of the motor case with a dry paper towel. Be especially diligent near the forward closure.

Stand the motor upright and pour 3/4 of the black powder ejection charge into the top of the forward closure. Save the extra black powder. You will need this and more when you build rockets that use dual deployment.

AeroTech supplies a paper disk to tape over the forward closure to hold the black powder into place. I’ve had this come unstuck, so I don't typically use it. One alternative is plain brown masking tape, covering the top of the motor and extending down the side of the motor. Another is to cover the black powder with the larger red plastic cup, which fits snugly over the forward closure (see Figure 4-25).

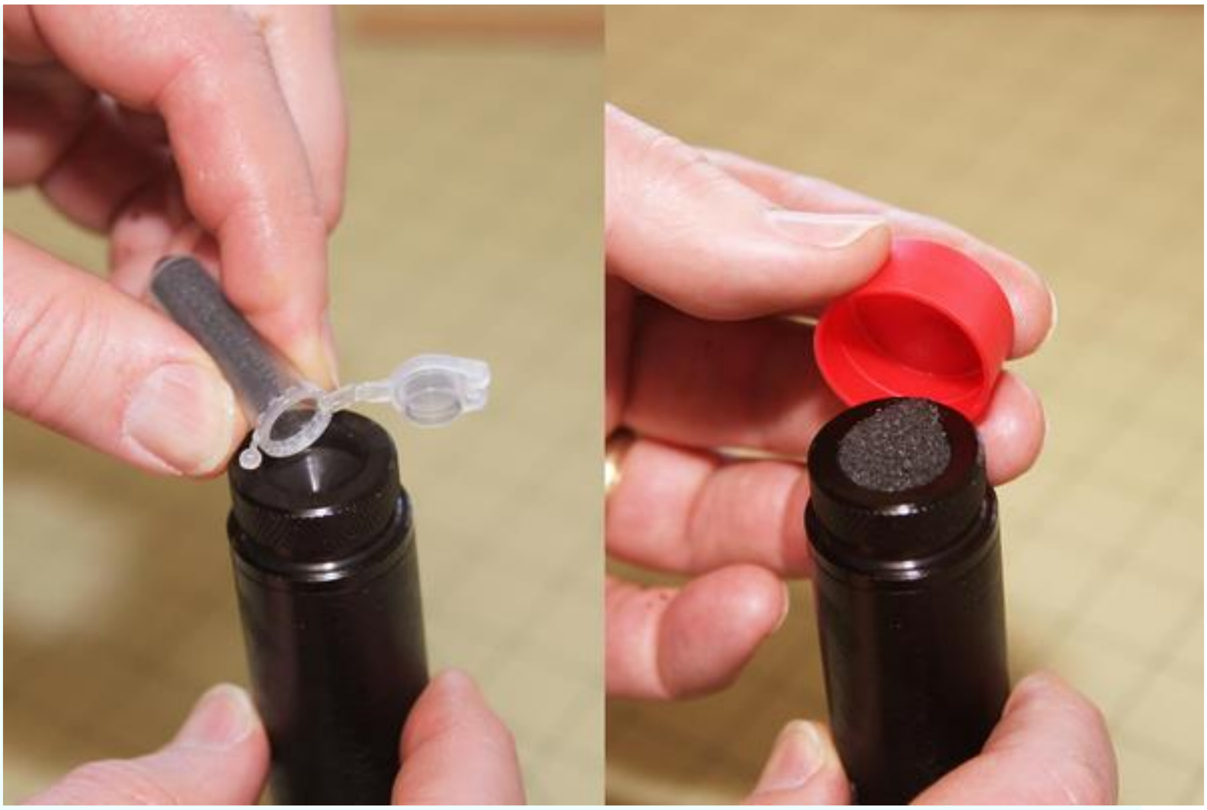


Figure 4-25. Pour 3/4 of the black powder into the top of the motor, then cap the front with the provided red plastic cup.

Once the cup is in place, stand the motor upright and gently shake it up and down. You want some of the black powder to drop through to the top of the delay element so it ignites as soon as the delay element burns through.

Use the second plastic cup to cover the aft end of the motor, sealing it from the elements until launch time (see Figure 4-26).

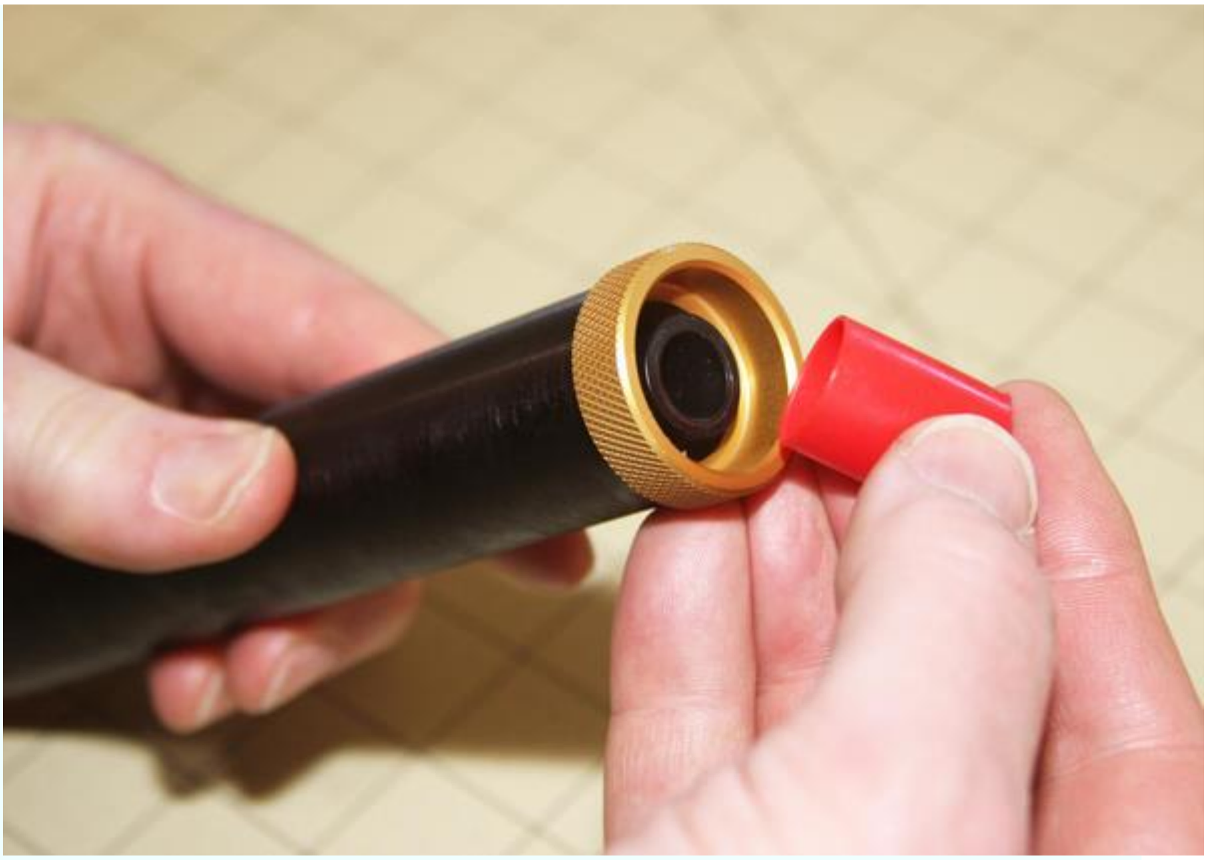


Figure 4-26. Cover the nozzle with the smaller plastic cup.

That completes the motor assembly. Set it aside until launch time. I generally wrap my motor in bubble wrap, then put a piece of tape across it and label the motor with the reload I've used. I wrap the igniter inside the bubble wrap with the motor. That might seem unnecessary, since you're about to stuff it into a rocket. What happens if the launch is scrubbed, though? This happens for all sorts of reasons, many of which are outside of your control. The wind might pick up, or an airplane might wander into the flight area. Clouds could move in—you are not allowed to fly a rocket into a cloud. Or perhaps your rocket is damaged during the trip to the launch site. In any case, you might end up waiting until another launch. It's nice to be able to pick up the motor a month or two later and be absolutely sure what is inside that case.

Here's a checklist for assembling the motor. With minor modifications it works for pretty much any AeroTech motor, from their smallest D motor through their giant 98 mm N motors. I'll admit this is one checklist I don't use much, though. The reason is that the motor itself comes with an instruction sheet that does a fine job as a checklist; just follow the photos at the right. If you are confused about a step or want to refresh your memory, the full written instructions are right beside the figures.

Remember, though, your Level 1 examiner needs to watch you assemble the motor. You can go over the parts and get familiar with the procedures before launch day, but wait until then to actually assemble the motor.

AeroTech H128W-M Assembly Checklist

1. Grease the three O-rings.
2. Insert the delay element and spacer into the delay insulator.
3. Place the delay O-ring around the delay element on the other side of the assembly from the spacer.
4. Insert the forward spacer in the forward closure.
5. Apply grease to the inside walls of the forward closure.
6. Insert the delay assembly into the forward closure, O-ring first.
7. Insert the three fuel grains into the motor liner.
8. Grease the outside of the motor liner.
9. Slide the motor liner into the motor case.
10. Place the forward seal disk against one end of the motor liner.
11. Place the thicker O-ring against the forward seal disk.
12. Screw the forward closure into the end with the forward seal disk and O-ring.
13. If needed, clear flash from the nozzle with a pencil.
14. Place the remaining seal disk against the motor liner.
15. Insert the nozzle, large end first.
16. Place the remaining O-ring against the nozzle.
17. Screw the aft seal into place.
18. Pour 3/4 of the black powder into the forward closure (use it all for rockets over 3” in diameter) and seal it with the large plastic cup.
19. Shake gently to settle some black powder against the delay element.
20. Place the remaining red plastic cup over the nozzle.
21. Tape the igniter to the rocket, and write “H128W-M” on the tape.

Building the Cesaroni H163-14A

Cesaroni Technology Incorporated (CTI) makes a complete line of solid-propellant ammonium perchlorate reloadable motors, as well as a nice line of hybrid motors. The solid motors are called their Pro-X series, where the X is replaced by the diameter of the motor casing. Case sizes include 24 mm, 29 mm, 38 mm, 54 mm, 75 mm, 98 mm, and 150 mm. Cesaroni's commercial motors include some P motors, which require an FAA Class 3 waiver!

Like the AeroTech reloadable motors, Cesaroni motors have two major parts, the motor case itself and the reload. There's another piece, though. While AeroTech handles the issue of changing the delay time by swapping out the delay element for one with a different size, Cesaroni has a device that allows you to change the delay time in the field. You need to have CTI's *Delay Adjustment Tool* (DAT), too. Each size motor has a different DAT, but the 29 mm motors like the H163-14A are a special case. They use the Pro-38 DAT from the Pro-38 motor line with an extra part called the Pro DAT Centering Ring. Both the Pro-38 DAT and the 29 mm Pro DAT Centering Ring are pretty common at launch sites, and you can probably borrow them from someone. Check beforehand with other club members, though. You don't want to miss your flight because the person who usually brings them didn't show up.

The Cesaroni motor hardware is usually sold in two pieces. The motor case is the gray tube in Figure 4-27. The black ring is the aft retainer, which holds the motor reload in place during the flight. There is no forward retainer on Cesaroni motors.

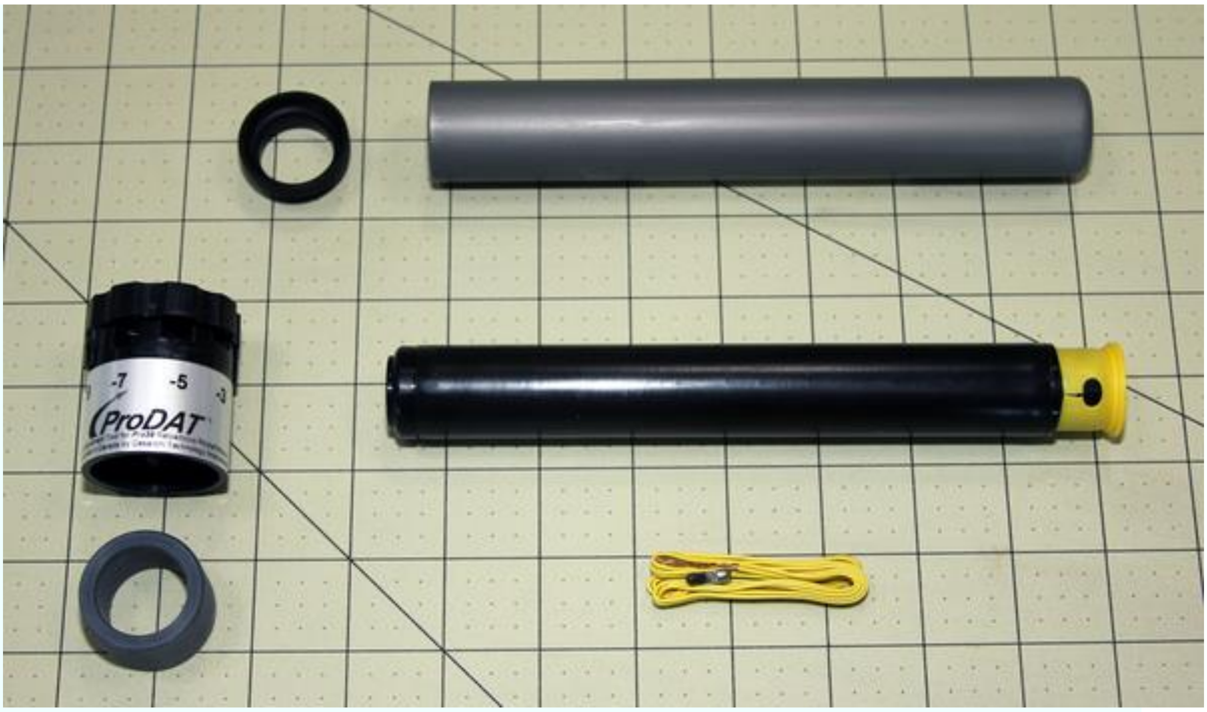


Figure 4-27. You need a motor case, aft retainer, reload, and Delay Adjustment Tool to prepare and fly the H163-14A.

Before you run out and buy your Cesaroni motor hardware, though, let’s take a look at how their line of hardware is set up. Until you get to the massive 150 mm O motors, all of the motors are designed around fuel grains that have a standard size for each motor diameter. The power of the motor is increased by adding more fuel grains and lengthening the motor case to handle the extra grains. The H163-14A is a 3-grain motor. There are a total of seven 29 mm motor sizes, 1H though 6G, with one to six grains, and the 6XL. So, to fly all of the various 29 mm motor reloads, you need seven cases, right?

Well, not really. It turns out that CTI has built spacers for its motors that are the same length as a fuel grain. The spacer fits in the front of the motor, allowing you to fly, say, a four-grain reload in a Pro-29 6G case when you use two spacers. Only two spacers are allowed at once, but that still means you can fly one- to six-grain reloads with just two cases: a Pro-29 3G case for one-, two-, or three-grain reloads, or a Pro-29 6G case for four, five, or six grains. You can also use spacers with the 6XL case, which is essentially a seven-grain case.

One choice for motor hardware is the Pro-29 Full Set (Figure 4-28). It comes with the P29-3G, P29-6G, and P29-6GXL cases, as well as two spacers, an aft closure, the Pro-38 DAT, and the Pro DTA Centering Ring.

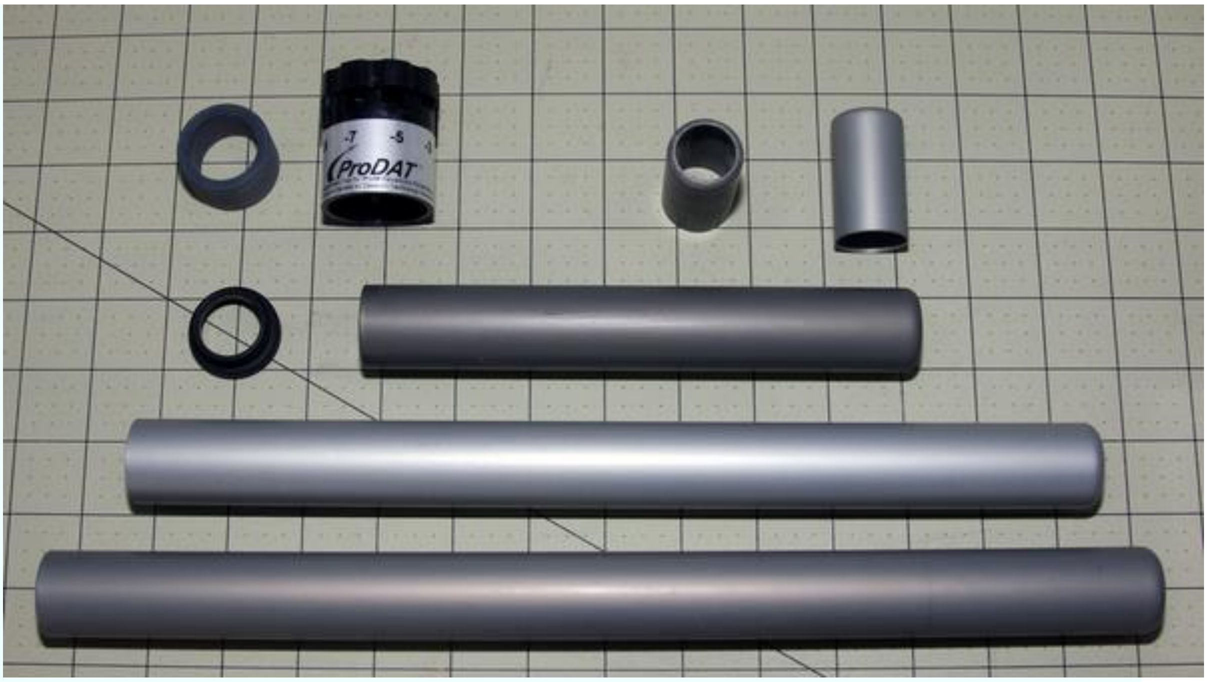


Figure 4-28. The Pro-29 Full Set—you can fly any of the CTI 29 mm reloads with this hardware combination.

The forward end of CTI motor cases is beveled inward, and the ejection charge is packed in a prebuilt section with the delay charge. Because of this design, there is no forward closure. There are two styles of rear closure. You will see the standard rear closure, as seen in Figure 4-29 as we start to build the motor. It overhangs the outer case a bit so motor retainers have something to grip. There is another rear closure that doesn't have this overhang. It's used for very low-drag rockets, but since there is no overhang, you need some way to keep the motor in the rocket other than a standard motor retainer.

NOTE

The 38 mm CTI motors don't have a reusable rear closure, so don't spend time looking for one when you buy your Level 2 motor. The aft closure on the 38 mm motors is integrated into the aft plug in the reload assembly. You just screw it into place and you're done.

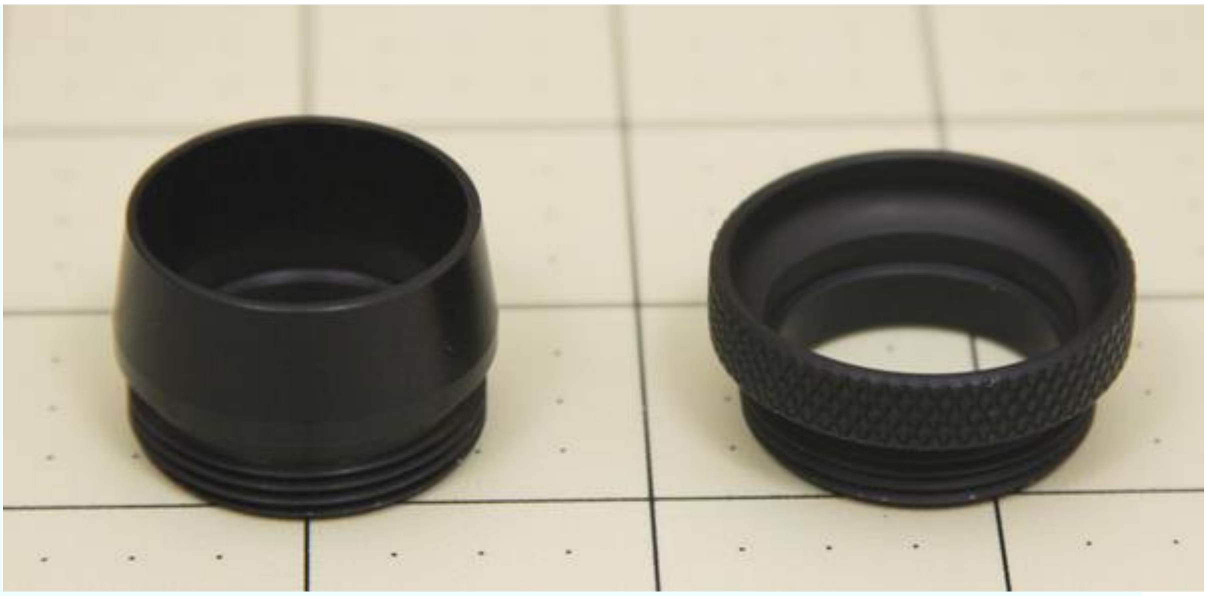


Figure 4-29. CTI uses two kinds of aft closure. On the left is the tapered closure, suitable for high-performance minimum diameter rockets. On the right is the standard closure.

There are some disadvantages to using a case with one or two spacers. First, the motor case is longer than necessary, and some rockets won’t be able to handle the length. (Callisto can handle the P29-6GXL case, so that won’t be a problem. Yes, the motor is about twice as long as the motor tube in the rocket, but it’s held securely in place, and there is enough room for the parachute in front of the long case.) The other disadvantage is that the case is heavier than it needs to be. That’s really only a problem on ultra-high-performance rockets, though. For the vast majority of situations, a three- and six-grain case is more than sufficient to fly CTI motors with one to six grains. You can add an XL case if you want to fly seven grain motors.

While vendors and simulators generally list the motor as this book does, calling it the H163-14A, CTI lists this motor as the 166H163-14A. Let’s take a look at what all of those numbers and letters mean.

The initial 166, which a lot of sources leave off, is actually a really useful number. There is a large range in the power of larger motors. H motors cover the range from 160 N-s to 320 N-s of total impulse. There is a really big difference between a 160 N-s motor and a 320 N-s motor. For Callisto, the 166H163-14A will carry the rocket to about 2,000 ft with a top speed of about 700 ft/s. The 315H255-14A will power the rocket to about 3,000 ft with a top speed of around 1,000 ft/s. They are both H motors, but the 166H163-14A delivers 166 N-s of total impulse, while the 315H255-14A packs almost twice that, coming in at 315 N-s of total power. And, of course, that's what the first number tells you. It's the total impulse for the motor.

You are pretty familiar with what H means by now. As you know, that means the motor has more than 160 N-s of total impulse and less than or equal to 320 N-s of total impulse. The next number, 163 in this case, is the average thrust in newtons, while 14A tells you the motor ships with a 14-second delay. The A indicates it is adjustable.

CTI has several fuel types, again to vary the power or provide special effects like smoke or colored flame. One of these that deserves special mention is the Skidmark. This motor sprays burning metal out of the nozzle, much like fireworks that use burning metal for their cool visual effects. There is some risk of fire with the Skidmark reloads, so you need to take special precautions when using them. The biggest is clearing a 70-foot-diameter circle around the launch pad, making sure there is no flammable material, especially dry brush, in that area. CTI also recommends having water and fire equipment on hand. Our own club generally doesn't allow flying these motors during the middle of summer, since our high mountain desert is almost always tinder-dry during summer. They are quite a sight when we do fly them, though!

Table 4-2 shows the current CTI fuel types. These don't show up in the motor designation, although some vendors add letters to indicate which formula the reload uses. In general, you need to check the CTI website to find out which formula a motor uses.

The CTI motors are remarkably easy to prepare for launch. Most of them are in what is called the hazmat shipping configuration, with the interior of the motor already assembled. In this configuration the reload for the H163-14A is prepackaged in a plastic motor liner, with the delay charge, ejection charge, nozzle, and so forth already in place. If you need a 14-second delay, all you have to do is slide the motor into a three-grain motor case, or a four- or five-grain case with the appropriate spacers, and screw the aft closure in place. You should add a small amount of grease to the threads of the aft closure for lubrication, but that's all there is to it.

Name	**Description**
Classic	The classic reload sports a yellow-white flame with a medium burn rat
Imax	With a slower, efficient burn, the Imax reloads are typically good for n These reloads have a yellow-white flame.
Skidmark	Sprays sparks from the nozzle for a distinctive visual effect. These hav with less power than other motors with the same number of grains. It's effects.
Pink	Medium burn times and a pink flame.
Blue Streak	Good overall efficiency, fast burn times, and a bright blue flame are ha Streak.
Red Lightning	Similar performance to the Pink, but with a red flame.
Smokey Sam	Trades some total impulse for a dense black smoke, for a very distincti
C-Star	This is the same propellant used in the Space Shuttle SRB. It has a med a high efficiency that gives these reloads high total impulse compared t same number and size of grains.
White Thunder	White flame and a fast burn rate that gives both speed and efficiency.
Vmax	These reloads are designed for speed! They have very, very fast burn ti average thrust compared to other similar-sized reloads.

Table 4-2. Cesaroni fuel types

Things get ever so slightly more involved if you need a delay of less than 14 seconds, which we do. In that case, you will need to remove the delay and ejection charge assembly so you can use the DAT to change the ejection delay. Cesaroni recommends doing this outdoors and at the launch site, so we're going to leave that step for launch preparations. There are three good reasons for doing this. The first is because you might decide to use the motor in another rocket which needs a different ejection charge. The second reason is that you will be drilling into a flammable material. Common sense says this is best done outside of the house. The third reason is that some very experienced people who build rocket motors for a living told you explicitly in their directions that you should modify the ejection charge outdoors. It’s good to pay attention to people with that much experience, especially the ones who still have all of their fingers.

All of this means you really don’t need to do anything at all with the CTI motor until you get to the launch site. Still, you’re dying to know what’s inside that motor, and there is the possibility that you will run across a motor that isn’t in the hazmat shipping configuration. It’s also cool to see how a rocket motor works.

With that in mind, let’s tear down and reassemble the motor so you have a working knowledge of how it will work and how to put it back together if the need ever arises. Pick a clean, dry working area away from any open flames. Gently twist the closures on either end of the motor liner to remove them. Each is held in place by an O-ring, and will slide out easily with a firm twisting motion. Remove the three fuel grains, and then remove the opposite closure. Lay all the parts out for inspection, as you see in Figure 4-30.

From the top left, you see the rear closure, the motor liner, and the ejection charge and delay charge assembly in the top row. The three fuel grains are next, followed by a cap used to hold the igniter in place as the chamber comes up to pressure, the nozzle assembly, and the motor case. The igniter is in the bottom row, still in its package. It should stay in the package until launch day.

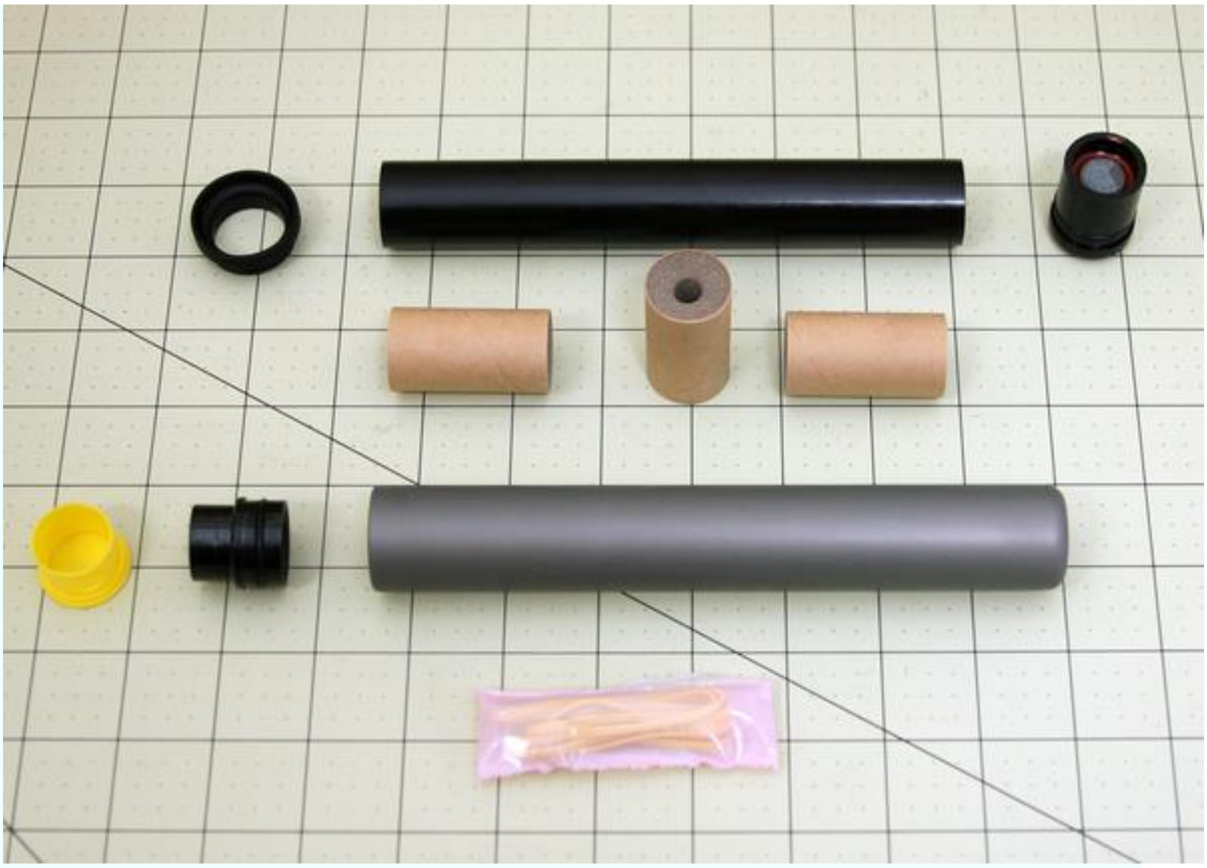


Figure 4-30. Tear down the motor and motor casing and lay out all of the parts.

WARNING

If any part is damaged, don’t use the motor. Doing so can cause a CATO.

Reinsert the delay and ejection charge assembly in the motor liner (see Figure 4-31). This caps the forward end. There may be a slight gap between the case liner and the base of the flange on the closure; that’s normal.

Take a look at the three fuel grains. One of them is different. The black pellet near one end is a Pyrodex charge used to help start the motor quickly. Pyrodex is a black powder substitute that is very common in the gun world. The igniter will ignite the Pyrodex, which will burn quickly, lighting the rocket fuel down the center of the motor. This is a hallmark of the smaller Cesaroni motors. They come up to pressure much more quickly and with a much more reliable ignition time than other high-power rocket motors. Larger motors, like a Level 3 M motor, don’t have this pellet.

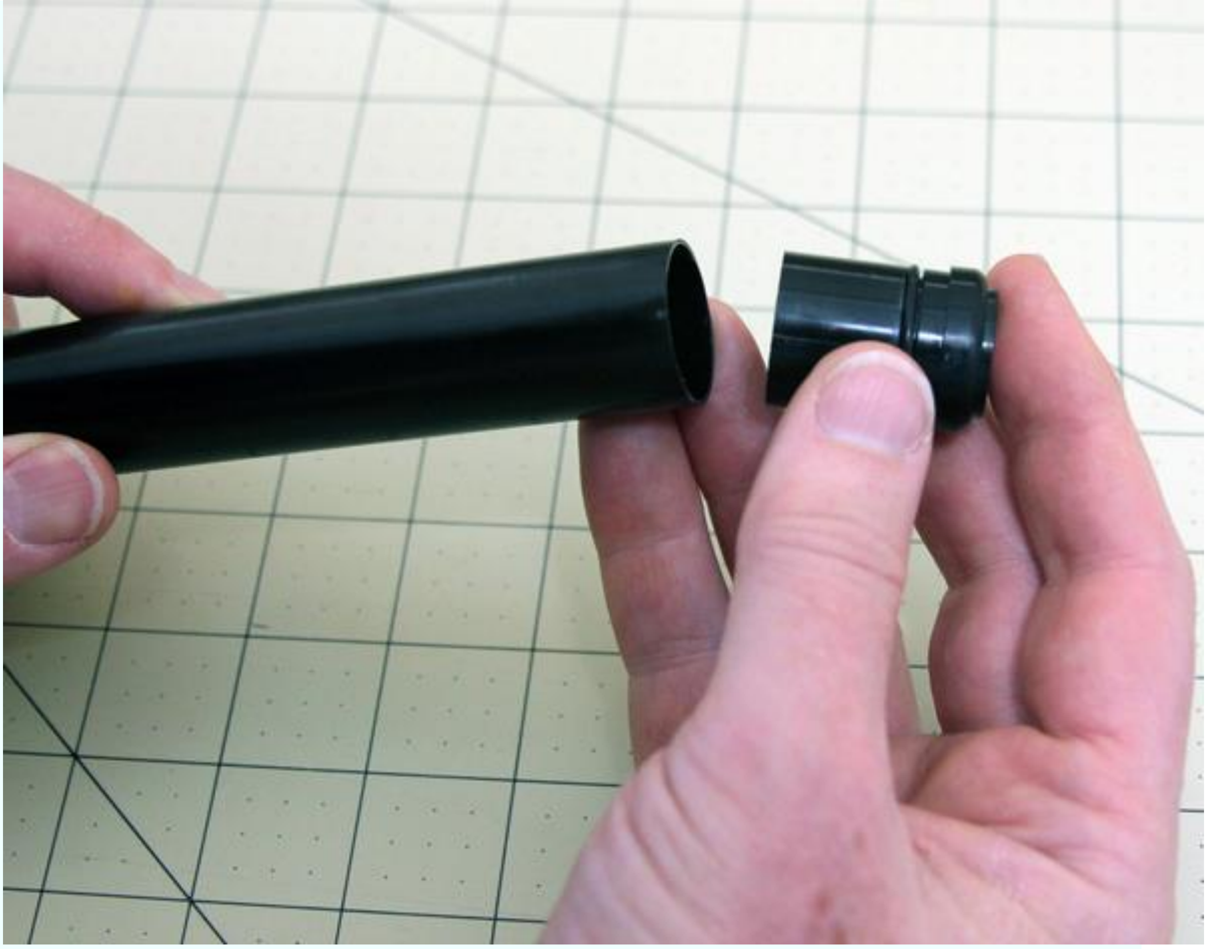


Figure 4-31. Insert the delay and ejection charge assembly.

Insert this grain first, with the Pyrodex pellet facing the delay charge at the base of the delay and ejection charge assembly (see Figure 4-32).

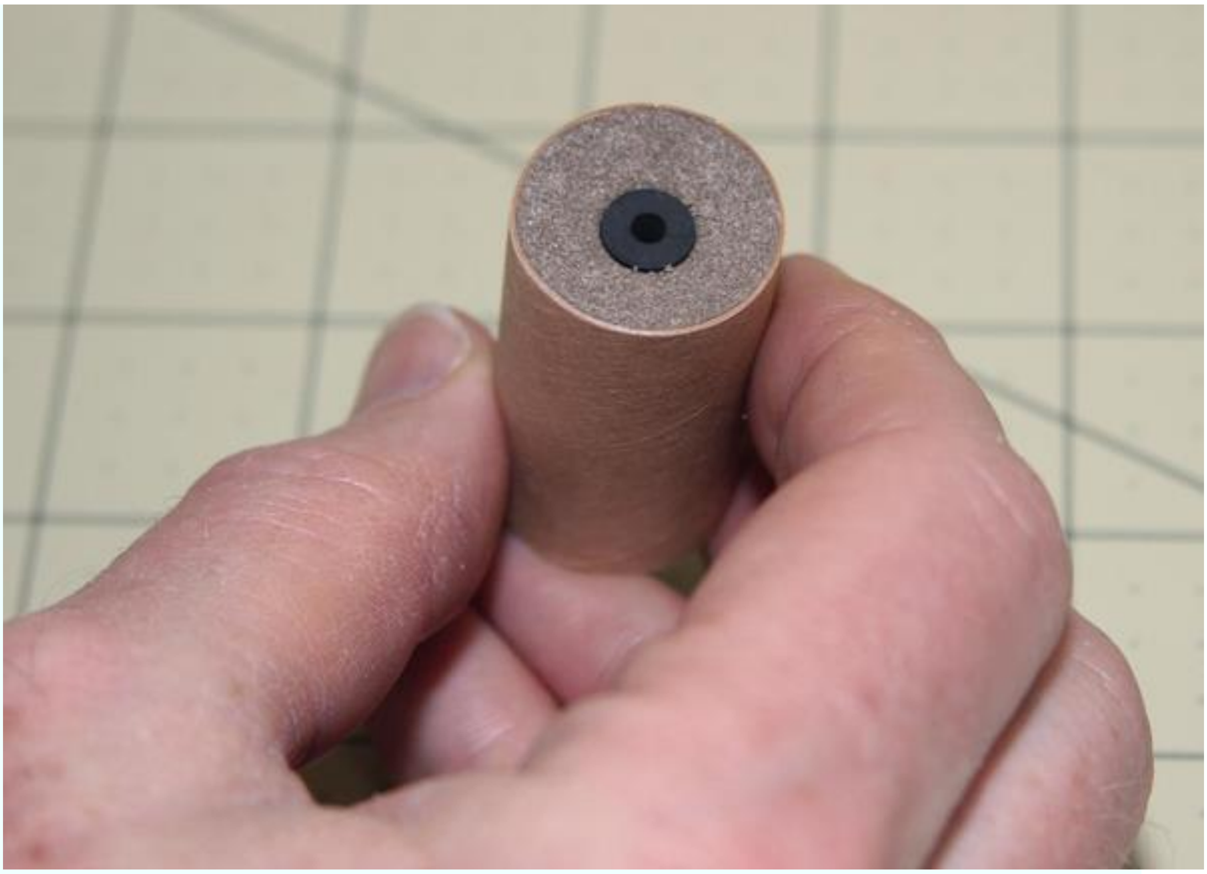


Figure 4-32. Insert the grain with the Pyrodex pellet first, with the pellet facing the delay charge.

Take a look at the remaining grains. One end is flat, while the other end is curved in slightly (see Figure 4-33). This allows the ends of the grains to burn, not just the central core. This is key to allowing the motors to burn with a fairly even thrust over the entire burn time, for reasons we'll see in Chapter 11. It is very important to insert the grains so the indented end faces toward the delay charge. Insert both grains.

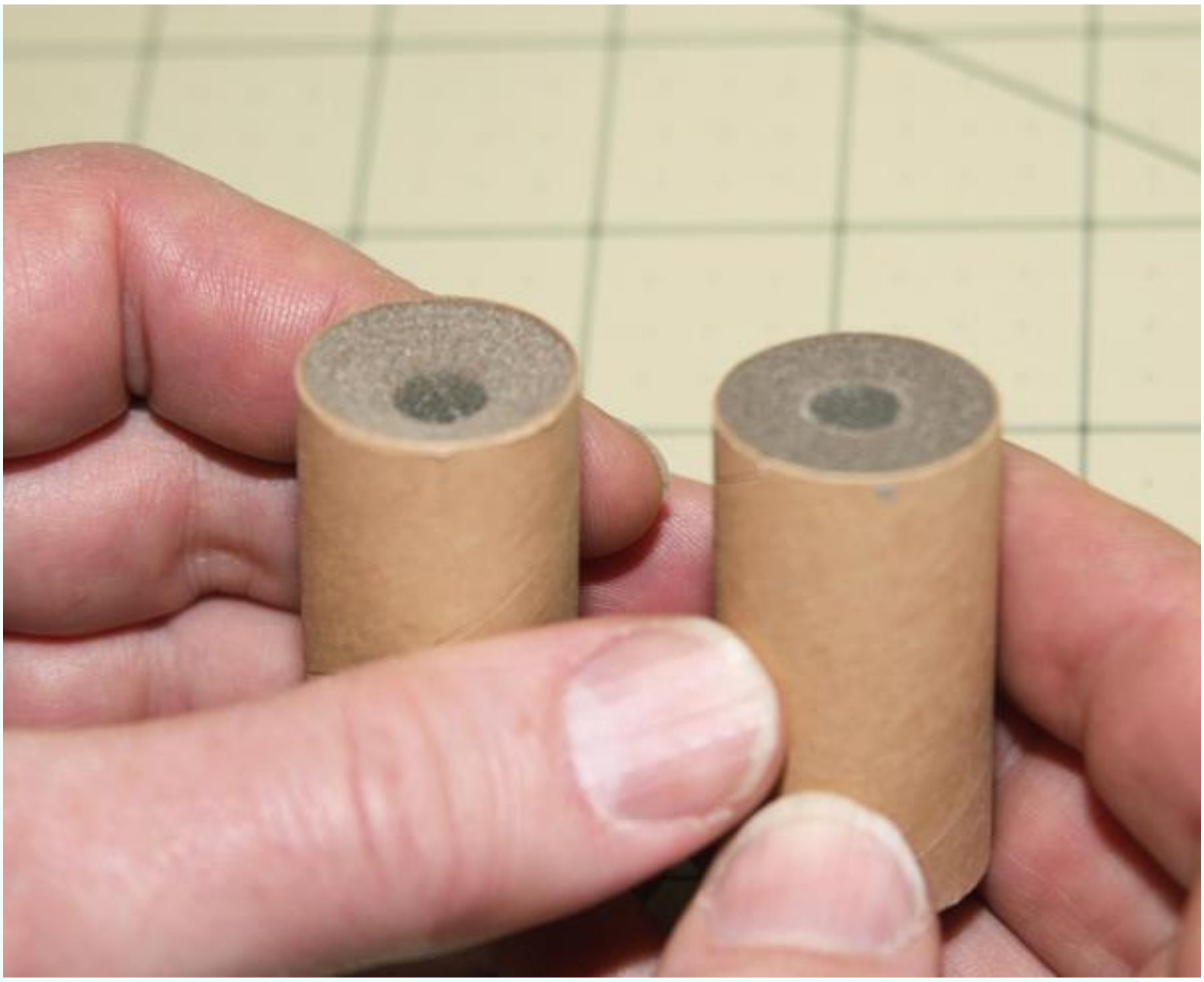


Figure 4-33. Insert the two remaining grains with the indented end facing forward, toward the delay charge.

Insert the nozzle assembly in the open end of the motor liner (see Figure 4-34).

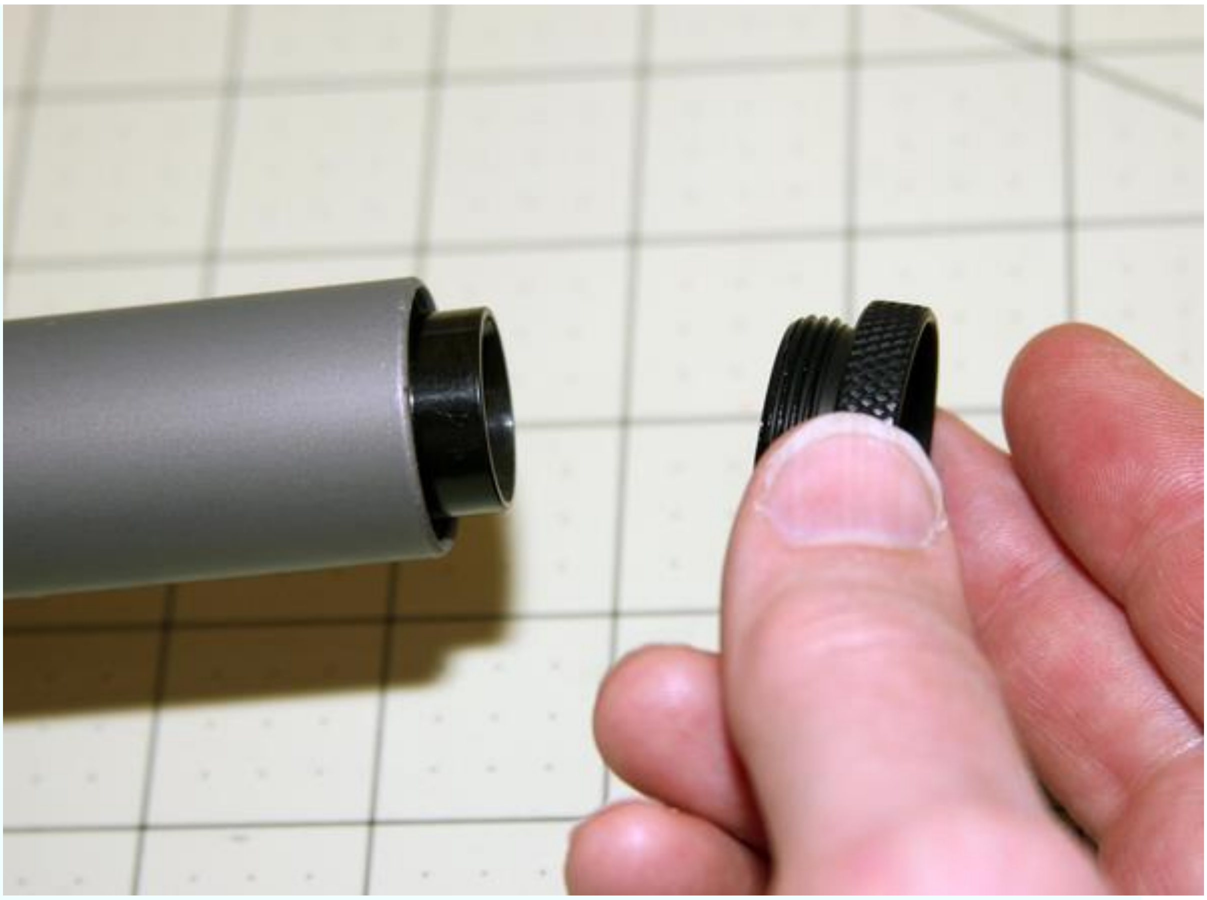


Figure 4-34. Insert the nozzle.

At this point, the motor is ready to slide into the motor case. Slide it in with the ejection charge facing forward and the nozzle toward the rear (Figure 4-35).

WARNING

Never use more than two spacers. Cesaroni tests its motors with two spacers, but not with more. You should never modify a motor, flying it in an untested configuration.

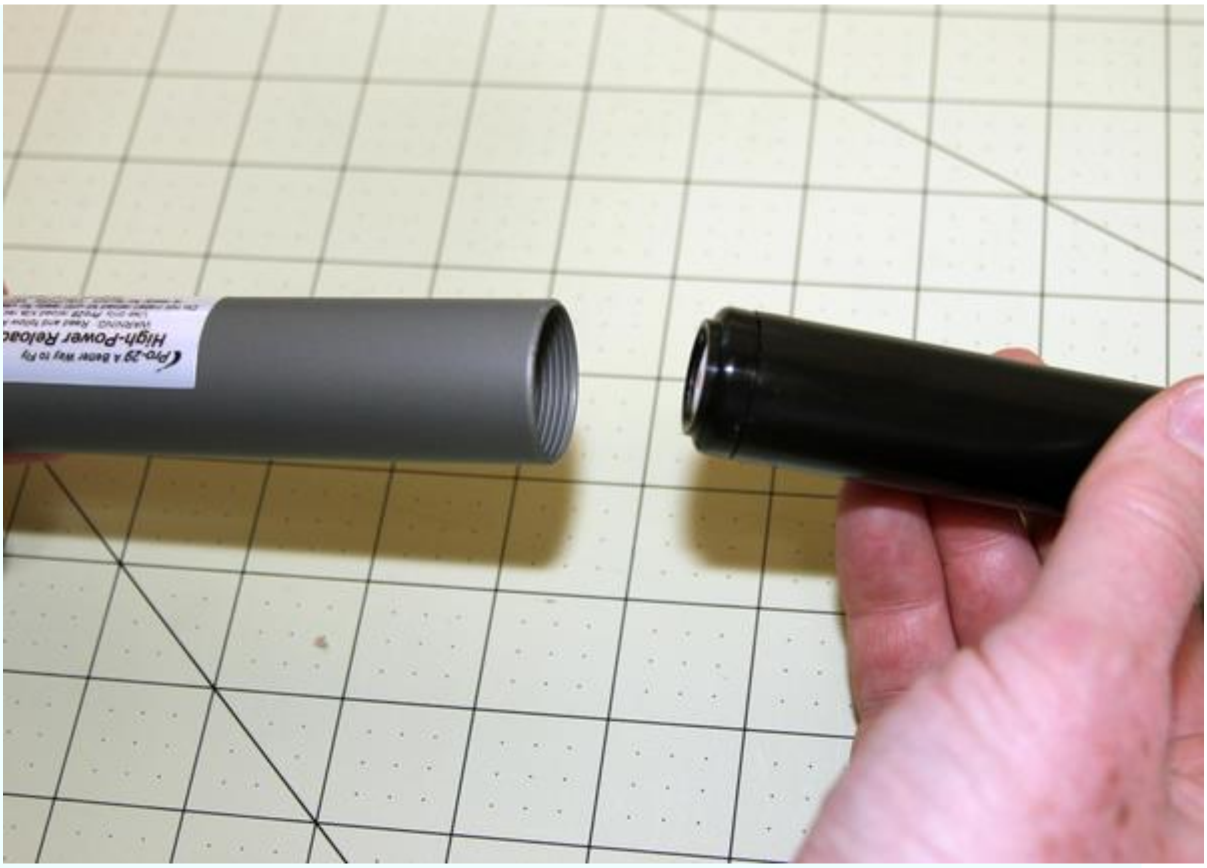


Figure 4-35. Insert the reload in the motor case, ejection charge first.

If you are using a longer case with spacers, insert the spacers before the motor. The spacers have a curved end and a flat end. The curved end goes in first.

Apply a light coat of grease to the threads on the rear closure if they are dry. Screw the rear closure into place, tightening it firmly by hand (see Figure 4-36). Do not use tools to tighten the rear closure.

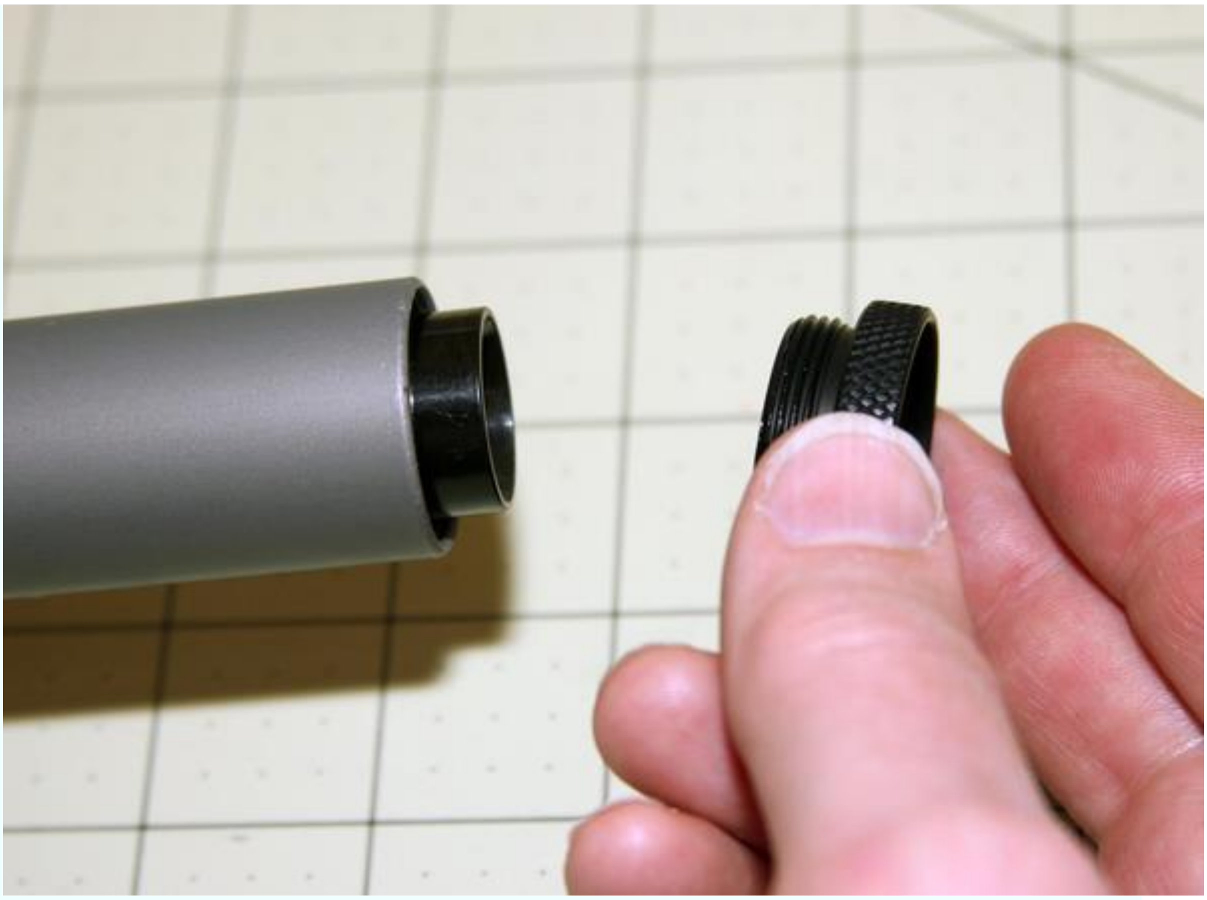


Figure 4-36. Screw the rear closure into place.

There will be a small gap between the base of the motor case and the flange on the rear closure. If it is more than 1/16”, something is wrong. Remove the motor from the case and identify the problem, correct it, and reassemble the motor.

Add the yellow plastic cap to the nozzle (see Figure 4-37). Push it down completely, so the hole is over the nozzle. You don’t want to leave a gap that would expose the motor to moisture or humidity. You will remove the cap again when the igniter is inserted, but that doesn’t happen until the rocket is on the launch pad and pointed in a safe direction.

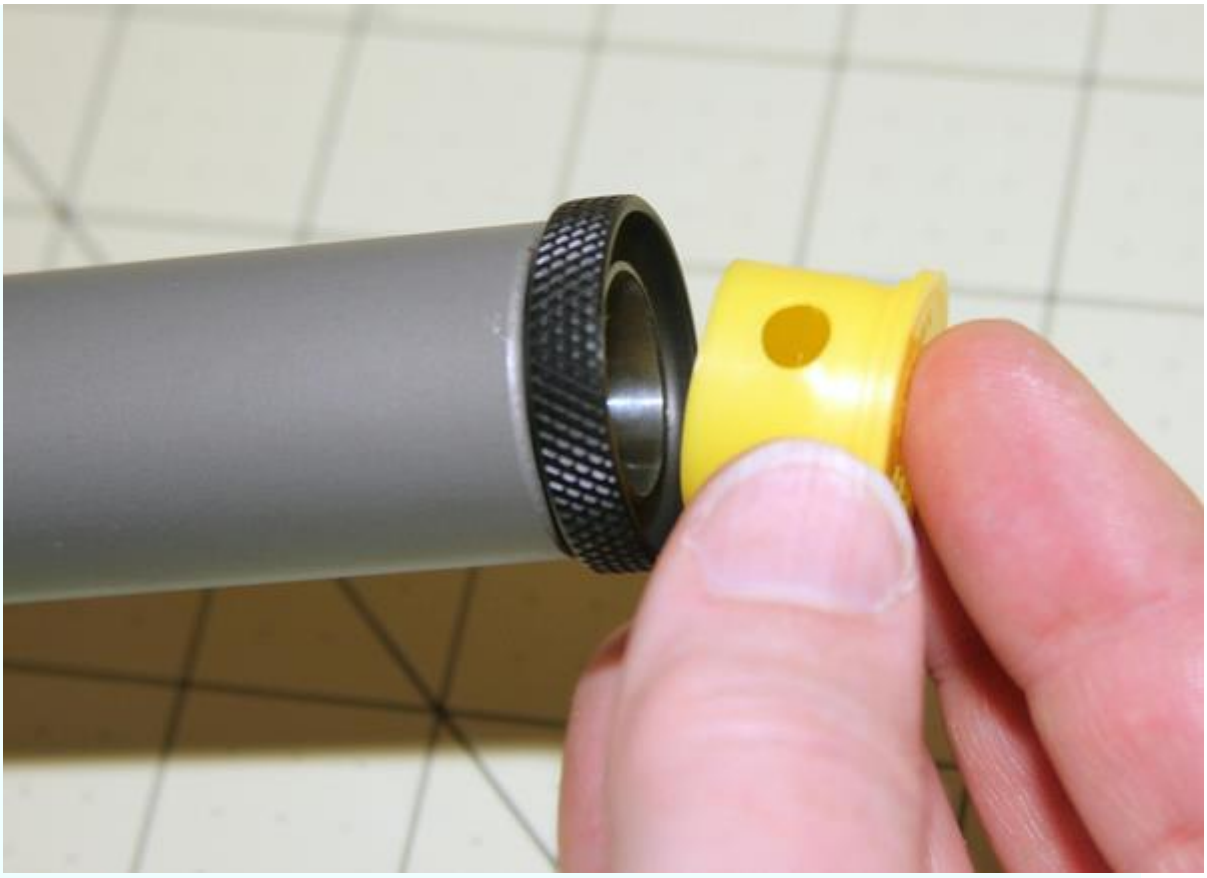


Figure 4-37. Push the plastic cap in place over the nozzle.

Cesaroni motor cases are shipped in a clear plastic tube with two black end caps. If you saved the tube, slide the motor back into the tube to protect it until launch day. It won’t fit all the way in, but you can add a piece of tape across the end to hold the motor in the protective tube. If you didn’t save the plastic tube, use bubble wrap or several layers of paper to protect the motor.

Tape the igniter to the side of the tube with masking tape. Write H163-14A on the tape. If the launch gets scrubbed, it might be a month or more before you get another chance to fly your rocket. You want to be sure you know what reload is in the motor when you are ready to fly.

Here’s a checklist for assembling the H163-14A, assuming it wasn’t shipped in the hazmat configuration or you needed to disassemble it for some reason. You don’t need to do anything until you get to the launch site if the motor is preassembled, though.

Cesaroni H163-14A Assembly Checklist

1. Insert the delay element assembly in one end of the motor liner.
2. Place the fuel grain with the Pyrodex pellet into the motor liner, pellet side first.
3. Slide the remaining two grains into the motor liner, indented side first.
4. Insert the nozzle assembly into the aft end of the motor liner.
5. Slide the reload assembly into the motor tube, delay end first.
6. Screw the aft closure into place.
7. Fit the yellow plastic cup over the nozzle, pushing it on until the hole is covered by the nozzle.
8. Place a piece of tape on the motor and write down the reload type.

Preparing the AeroTech H135W-14A

AeroTech also makes a line of single-use motors. These motors use a disposable fiberglass motor case. While there is still a little set-up required before using the motor, it’s pretty minimal and can easily be taken care of at the launch site. You will need two things to use the H135W-14A motor: the motor itself, and the AeroTech Universal Delay Drilling Tool. Figure 4-38 shows the motor in its yellow packaging tube, along with the various parts. The Universal Delay Drilling Tool is on the left. The motor itself is on the bottom, with the igniter, ejection charge, and protective plastic caps in between. The larger red plastic cap usually covers the nozzle when the motor is removed from the package, and can be left there for now.

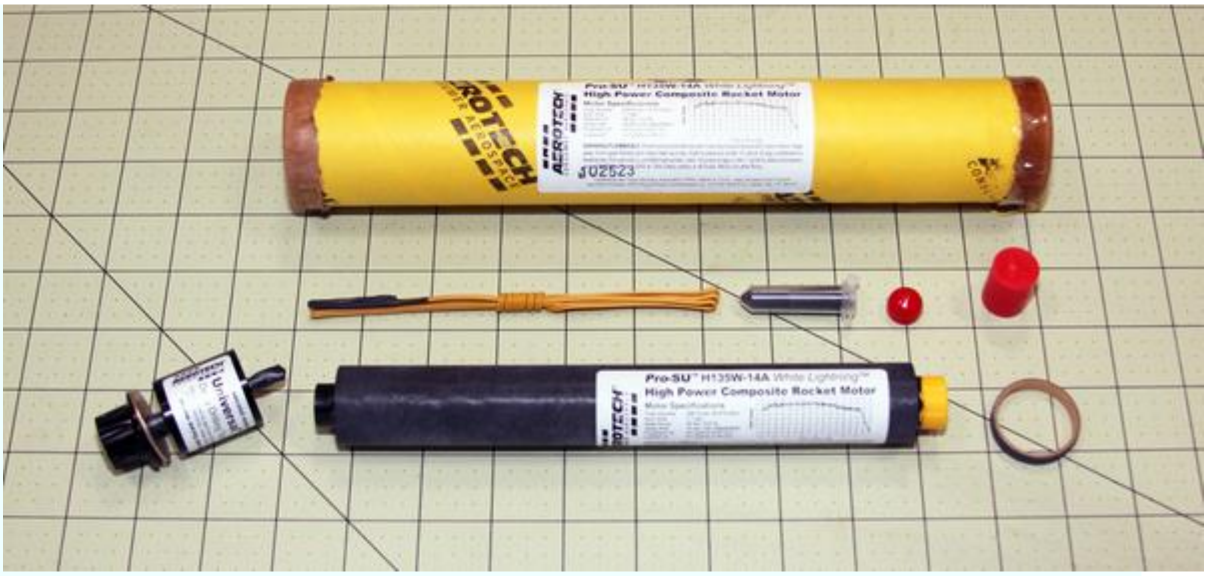

AEROTECH
Pro-SU H135W-14A White Lightning
High Power Composite Rocket Motor
J02523
Pro-SU H135W-14A White Lightning
High Power Composite Rocket Motor
AEROTECH
Universal

Figure 4-38. The AeroTech H135W-14A motor with the Universal Delay Drilling Tool.

Nomenclature for AeroTech’s single-use motors parallels that of its reloadable motors. As before, the motor designation starts with a letter indicating the total impulse. In this case, the H tells us this motor has more than 160 N-s but no more than 320 N-s of total impulse. The average thrust is 135 newtons, and the motor uses White Lightning fuel. (Refer back to Table 4-1 and the corresponding text for information about the kinds of fuel AeroTech uses.) The ejection delay is 14 seconds, and the A indicates this is adjustable.

Once you are at the launch site, the first step in getting the motor ready is to adjust the delay time. Take a look at the delay tool. There is a metal washer and a drill bit that slips through the body of the tool. You can remove 2, 4, 8, or 10 seconds from the delay time as the motor ships by pointing different ends of the delay tool at the motor as you drill out the delay charge and either using or not using the disk. According to simulations, the ideal delay time for Callisto using this motor is about 8.9 seconds. Going a bit over to give the rocket time to reach apogee and tip over before the parachute is deployed, we’ll aim for a 10-second delay. That means we need to remove 4 seconds from the default delay for the motor.

Remove the brass washer and set it aside. Insert the drill bit so the drill bit is on the end labeled “–4 seconds removal end faces motor” and the cap is on the end labeled “–8 seconds removal end faces motor,” as you see in Figure 4-39. Slide the tool over the end of the motor with the yellow cap. This will cause the drill bit to push back out of the case a bit.

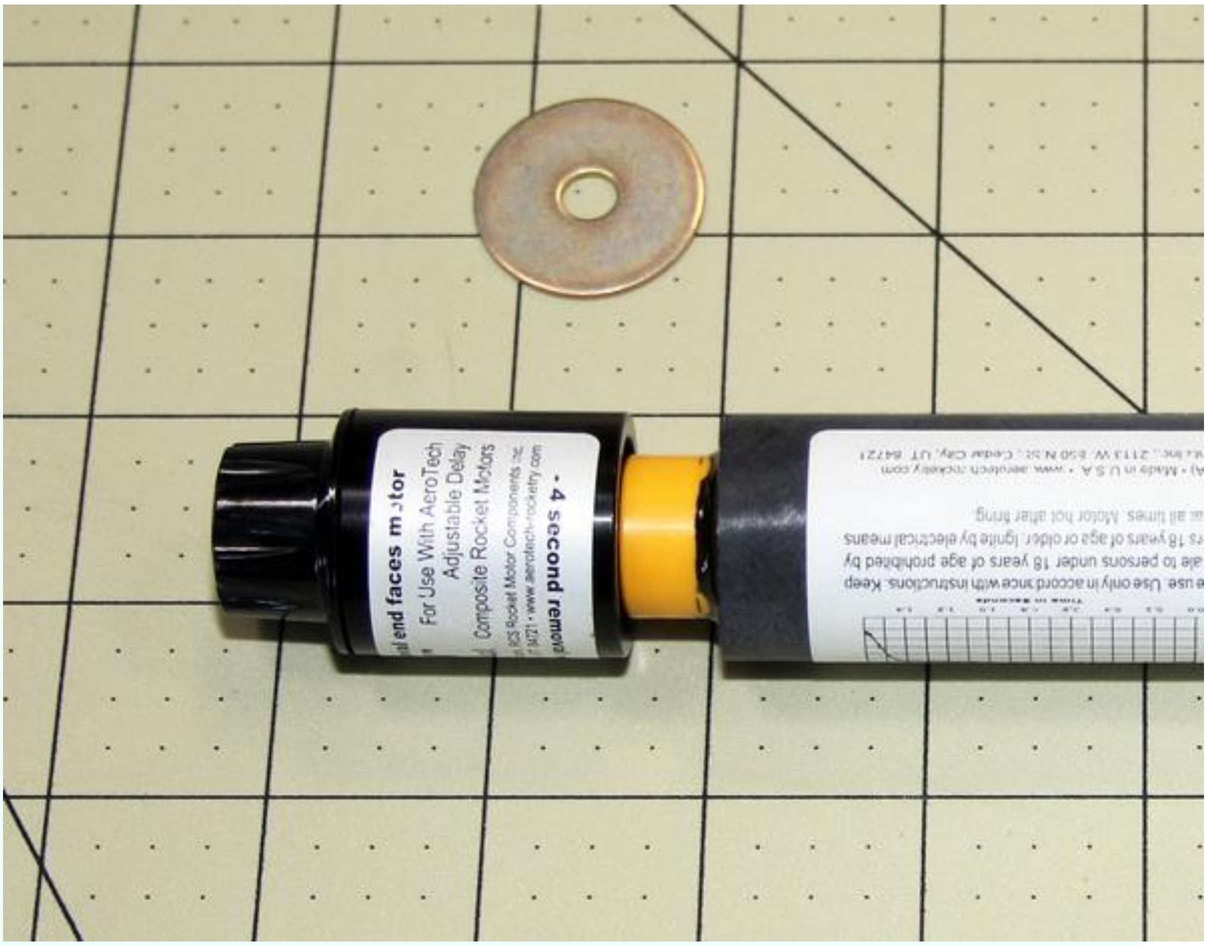


Figure 4-39. Remove the brass washer. Insert the drill bit so the –4 second label is on the side the drill sticks out of. Drill out the excess delay material.

Rotate the cap clockwise to drill out the excess delay material. Keep drilling with a slow steady pressure until the cap and delay tool both fit snugly against the yellow cap on the motor. Remove the tool and shake any excess delay material into a plastic bag for temporary storage. Be sure to get the material from both the end of the motor and around the drill bit.

Shake about half of the black powder from the plastic container into the yellow tube (Figure 4-40). You'll use all of the black powder for a 3"-diameter rocket like Deimos from Chapter 6. You may need to add even more black powder for a very large-diameter rocket. "Predicting the Recovery Charge Size" tells you how to calculate the proper amount of black powder.

Use the remaining red plastic cap to hold the black powder in place (see Figure 4-41). You can add a piece of masking tape or painter’s tape if you like, or even substitute the tape if you drop the plastic cap somewhere inaccessible.

Figure 4-40. Shake about half of the black powder into the motor.

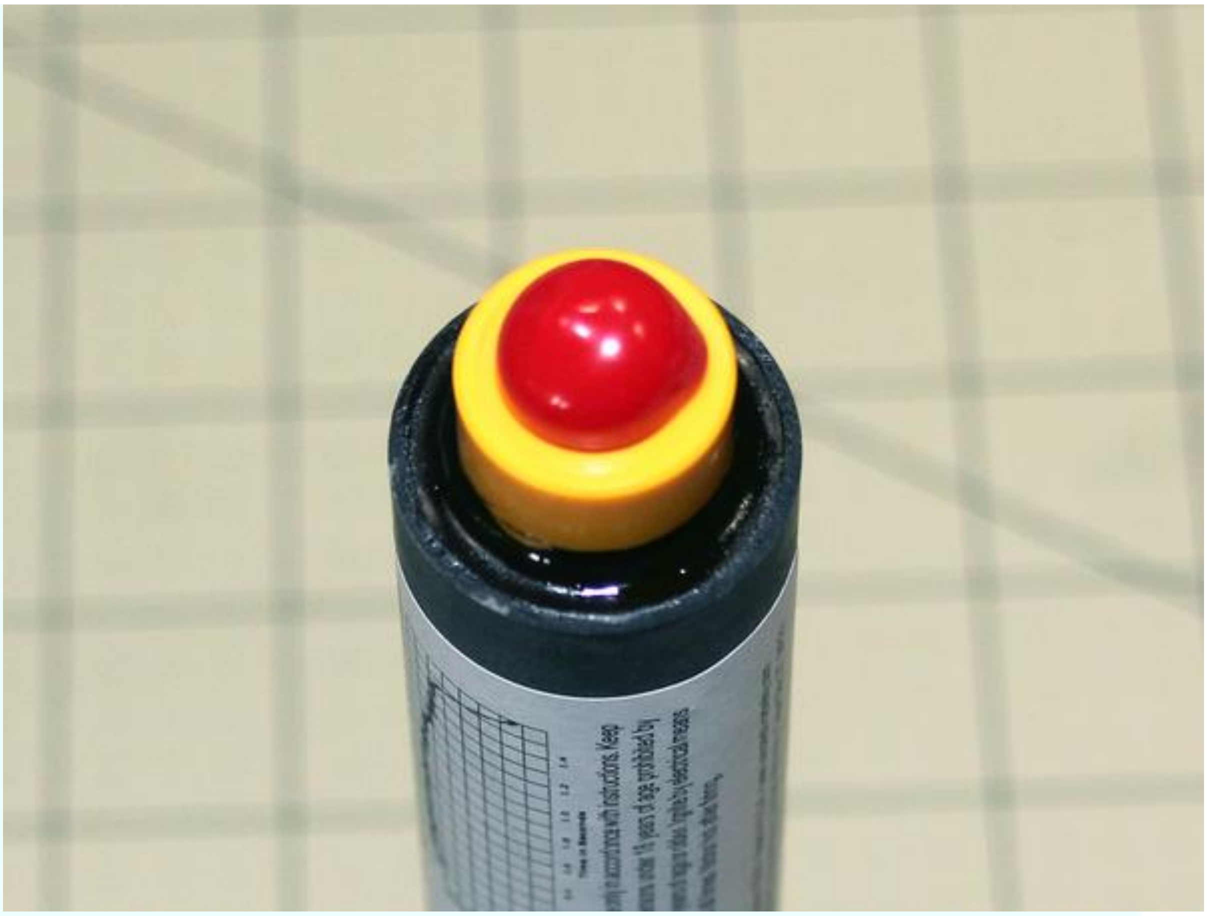


Figure 4-41. Add the small red plastic cup to seal the black powder.

Since you probably did all of this at the launch field, the safest place for the motor at this point is in the rocket. Remove the outer retaining ring, slide the motor into place, and screw the retaining ring into place, tightening by hand. Tape the igniter to the side of the rocket with masking tape or painter's tape. The igniter is never installed until the rocket is on the pad and pointed in a safe direction. Here's a checklist for assembling the H135-14A.

AeroTech H135-14A Assembly Checklist

1. Use the Universal Delay Drilling Tool to change the delay from 14 seconds to 10 seconds.
2. Pour half of the black powder into the forward end of the motor.
3. Fit the red plastic cap in place to contain the ejection charge.
4. Install the motor in the rocket.
5. Tape the igniter to the side of the rocket.

Chapter 5. The Level 1 Certification Flight: Launch

Launch Day!

The big day has arrived! Let's look at what you should take and what to expect.

What to Take

There are a number of things you will need to take with you. We've talked about all of them, other than a few personal items. You need to take your rocket, motor, and paperwork, of course. The launch site will probably be fairly remote. You can check with the members of your local rocket club to be sure, but in most cases you will want to take water, snacks, or lunch, and whatever you need to be comfortable outdoors for several hours. Refer to the following checklist when you're getting ready. I'm sure you will make adjustments to this list, adding or removing items as necessary to deal with your local environment.

What to Take

Rocketry supplies

- Rocket
- Motor case with closures
- Motor reload
- Parachute
- Flame-proof parachute protector
- Level 1 paperwork

Spares and field repair

- Spare igniter
- Super glue or fast-drying epoxy
- Screwdriver and pliers

- Flashlight (for peering into the body tube)
- Hobby knife

Personal items

- Camera
- Sunglasses
- Sunscreen
- Warm clothing
- Hat
- Portable chair
- Water
- Snacks or lunch
- Folding work table
- Binoculars
- First aid kit

The Safety Code

Both TRA and NAR have a safety code for high-power rocketry. The safety code is a set of rules put together by experts in the field based on past experience. It is designed to keep everyone at the launch site safe, and to minimize the likelihood that there will be damage to property. You are expected to follow these safety codes at all times. If you don’t, a variety of things might happen. First, if there is a mishap, it’s likely the insurance won’t cover it if you deliberately violated the safety code. It’s also likely your Level 1 examiner will decide you are acting in an unsafe manner, which could disqualify your certification attempt. Remember, the examiner has a lot of latitude. Repeated violations could get you an invitation to leave, since no one wants to be around an unsafe flier. They also don’t want you to tarnish the reputation of the group or sport.

The NAR High Power Rocket Safety Code (August 2012 revision) is reprinted here. The safety code itself is shown in bold, and I’ve added commentary to explain certain parts. These comments are not part of the safety code itself.

See Appendix B for both the NAR and TRA high-power safety codes. You should also visit the National Fire Protection Association (NFPA) website and read NFPA 1127: Code for High-Power Rocketry. The NFPA is one of the organizations that helps regulate hobby rocketry in the United States. While NFPA codes are not laws, they are frequently used as the basis of laws by state and local governments. NFPA 1127 is also the basis for the TRA safety code and many of the procedures you will see at the launch site. It is integrated into the NAR safety code.

NAR High Power Rocket Safety Code Effective August 2012

1. **Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.**

Basically, this means you have your certification or are trying to get it.

2. **Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.**

High-power rockets are made with more durable materials than low-power rockets. If the rocket needs them, you can use fiberglass, carbon fiber, metal-tipped nose cones, aluminum fins, and so forth.

That doesn’t mean you should use these super-strong materials indiscriminately, though. They definitely increase the risk of damage when something goes wrong. NAR is urging you to design with the lightest, safest materials possible for a particular rocket. If your rocket does go out of control and hit something, you want the rocket to crumple. That reduces the damage the rocket will do to everything but itself, and if your rocket happens to hit something you care about, you’ll definitely want the rocket to give way.

3. **Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.**

Both NAR and TRA certify motors, and maintain lists of certified motors on their websites. NAR rules require you to use these motors. TRA does have a program for experimental motors. We'll look at that in Chapter 14.

4. **Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.**

The launcher will probably be a club launcher or one you've borrowed from a club member, and should follow all of these requirements.

5. **Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.**

Some rocket motors, especially high-power rocket motors, start rather slowly. I have seen them sit on the pad for tens of seconds with no indication anything was happening before suddenly lighting and leaping off of the pad. This requirement keeps you from walking up to a smoldering motor that is about to take off.

6. **Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one**

high power rocket I will observe the additional requirements of NFPA 1127

Table 5-1 lists the safe distances set forth by NAR.

The best way to check the stability of a rocket is exactly what we did in Chapter 2. Find the center of pressure with a simulator and the center of gravity by direct measurement. Make sure the center of gravity is at least one body tube diameter in front of the center of pressure.

You need to repeat these checks even when a rocket has flown before. Changing the motor, the payload, or even the parachute will shift the center of gravity. You should always verify that the rocket is still stable in the new configuration.

7. **Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.**

The best way to check launch rod length is with a simulator, as discussed in "Simulating Flight".

You may see clubs flying under TRA rules with different blast deflection mechanisms. I'm not convinced it is ever really a good idea, though.

Motors that use titanium sponge in the propellant shoot out sparks as a visual effect. AeroTech calls this propellant type Metalstorm; CTI calls the motors Skidmark motors. You may also hear them referred to as sparky motors. It's also a good idea not to fly these motors at all in dry, fire-prone conditions.

8. **Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.**

You may recall that 40,960 N-s is an O motor, the largest motor allowed without a special FAA clearance. It’s also the largest motor NAR allows, period. TRA does allow larger motors at research launches, covered in Chapter 14.

The maximum liftoff weight is usually too lenient. You will need a ridiculously long launch rod to get away with a thrust to weight ratio of 3. The requirement comes from the National Fire Protection Association guidelines, which are laws in many jurisdictions in the United States. This requirement is discussed in detail in Chapter 11.

9. **Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.**

These are basic safety practices that will be enforced by the club. They are also laws in the United States.

10. **Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).**

See Table 5-1 for the minimum launch site sizes. Your local club will set up the site so you follow this rule.

11. **Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.**

Again, this is a basic safety requirement that the club will enforce.

12. **Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.**

TRA is stricter, at least for the certification flight. You must use a parachute for your rocket on certification flights. Other recovery methods are allowed later, though.

13. **Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.**

When I was doing research for *Make: Rockets*, which deals with low-power rockets, water rockets, and air rockets, I found that there had been four deaths associated with model rocketry. When Ted Chochran, president of NAR, was looking through the finished book, he sent a note informing me that there had now been five. While five deaths in six decades doesn’t seem bad compared to many activities, like bicycling or football, there is something very regrettable about these five deaths. You see, *every single one of them* could have been avoided by following this rule. Each of these deaths occurred when someone tried to recover a rocket from a power line.

A rocket on a power line is lost. You can photograph it, and you can even get credit for your certification launch, but the only way to get it back is if the power company removes the rocket. They may just do that—it’s heavy enough that they might want to clear it from the line. Let them know about the rocket and see, but please *do not* try to get it back yourself.

Unfortunately, there has now been one additional death from a model rocket. This is the first one that was not caused by a power line. It involved a rocket very much like Callisto. The rocket’s recovery system failed, and the rocket returned ballistically, hitting one of the fliers.

This should bring home the seriousness of safety precautions when flying rockets like the ones in this book. Unlike low-power rockets, high-power rockets are safe because of the procedures we follow, not because the rockets themselves are built of safe materials. We’ll return to the topic of the energy of impact of a rocket in “Parachute Rocket Science”, but it is enough that you don’t want to be under the rocket, even if it is returning with a fully deployed parachute.

Installed total impulse (Newton-seconds)	**Equivalent high power motor type**	**Minimum diameter of cleared area (ft.)**	**Minimum personnel distance (ft.)**	**Mi dis roc**
0–320.00	H or smaller	50	100	20
320.01–640.00	I	50	100	20
640.01–1,280.00	J	50	100	20
1,280.01–2,560.00	K	75	200	30
2,560.01–5,120.00	L	100	300	50
5,120.01–10,240.00	M	125	500	10
10,240.01–20,480.00	N	125	1000	15
20,480.01–40,960.00	O	125	1500	20

Table 5-1. Minimum distance table

Note: A complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

What to Expect at the Launch Site

How the launch site is organized depends a lot on how many people are there. For a small local launch, you may find a few people with their cars set up in a field and launchers at varying distances from the cars. At a large launch, like NAR’s NARAM or TRA’s BALLS, you might find ropes or cones to guide traffic to parking areas and a launch area cordoned off with rope. Whatever the setup, look for the launchers and stay away from that area until you have permission to head out there.

There are basically four roles at any launch. Let’s take a look at what these roles are and how they impact your certification flight.

RANGE SAFETY OFFICER

The Range Safety Officer, or RSO, is in charge of overall site safety. In some areas this person is called the *Launch Safety Officer*, or LSO, but it’s the same role. Whatever the name, it’s the RSO who decides whether operations at the launch site are safe. The RSO might stop launch activity due to wind, aircraft, or even an unruly crowd. The RSO can stop a particular flight because a rocket doesn’t look stable or properly built. Whatever the decision, the RSO always has the final word on any safety issue. It’s not a democracy. If the RSO makes a decision, you have two choices: abide by the decision or leave.

LAUNCH CONTROL OFFICER

The Launch Control Officer, or LCO, is also called the *Range Control Officer* (RCO) in some areas. This is the most visible role at the launch site. The LCO is responsible for laying out the site, setting up launches, controlling traffic to and from the launch pads, and either handling the launch pad controls or overseeing the launch pad controls if someone else is allowed to push the launch button.

While the roles of RSO and LCO don’t change, their visibility and who performs the roles can vary dramatically with the number of people at the launch site. With a single pad and a couple of people who fly together frequently, both roles may float to the person whose rocket is flying. At a rocket club launch where there is more than one pad or a large crowd and several flyers, the LCO will be a very visible role. The LCO won’t be flying a rocket, at least not while performing the role. The LCO may also designate a person to check in rockets, making sure they appear to be stable, properly constructed, and properly prepared. At a small launch, the LCO and RSO might still be a single individual, but at a large launch these roles are clearly separated so the LCO can concentrate on the mechanics of controlling people and flying rockets while the RSO can watch overall safety.

FLYER

That’s you! The flyer is the person whose rocket is being flown. When you arrive at the launch site, check in with the person who will supervise your certification. They can tell you about local customs and conditions, and tell you how to check in your rocket and get a pad assignment. Unless you are at a very small launch, you will probably be asked to fill out a flight card and turn it in to the LCO. The LCO will assign a pad and tell you when it is OK to approach the pad, generally by calling “The pads are safe” over the PA system. Even so, the number of people who approach the pad should be kept to a minimum. You and your examiner will go out, and it’s not uncommon for a photographer to join you. This is not the time to invite your entire family out, though. The number of people at the pad is kept to a minimum to reduce the distractions and minimize the number of people who might be affected by any accident.

Once the rocket is prepared, you and everyone else will retreat behind the launch controllers. Depending on the size of the launch, you may end up operating the launcher yourself, or you might simply watch as the LCO runs through the various pads, launching one rocket after another. If you really want to push the launch button yourself, ask. Most LCOs are willing to let you do it. If so, once everything is ready, you will count down loudly from five, pushing and holding the launch button for a second or so. The rocket won’t ignite instantly, so hold the button down until you see smoke. If the rocket doesn’t light, you will need to wait one minute before approaching the rocket. I’ve seen rockets sit on the pad for several seconds after the launch button was released, then suddenly leap into the air.

Assuming all goes well, your rocket will lift off at a high rate of speed. If you record the flight on video, you might not get a single frame with the rocket under power, although there will generally be one or two frames. It’s really that fast. Callisto will soar about 2,000 ft into the air, pop its parachute, and descend slowly to the ground. You are generally allowed to go get the rocket if it lands behind the launch control table, but if it lands in the direction of the launchers, you need to wait until the LCO says the pads are safe before going after the rocket.

SPECTATOR

There are usually people at the launch who are not flying a rocket. Perhaps you brought your family along to see the flight. There might be a club member who has nothing to fly, but wants to join the fun to see what others are doing. Curious locals may stop by to see what is happening. Regardless of who the spectators are, being a spectator at a high-power rocket launch is an active role.

Spectators must stay out of the area with the launch pads unless invited to enter. They should also not recover a rocket unless the flyer gives them permission. Many high-power rockets use pyrotechnic charges to eject parachutes; these may not all fire. It’s important to let the flyer recover the rocket and disarm any remaining charges.

Spectators must pay attention to the launch, and are frequently asked to stand. That’s so they can dive out of the way quicker if something goes in an unexpected direction. On many occasions I have seen an RSO postpone a launch until all the spectators stopped talking and faced the launch pad.

Preparing the Rocket

Once you understand the operation of the site, it’s time to get your rocket ready. Fill out your flight card and give the Level 1 paperwork to your certification official. Assemble the motor in their presence. If you are using an AeroTech motor, trim a small opening in the red plastic cup that covers the nozzle. The opening should be about 1/16” to 1/8” wide (see Figure 5-1). You can pull the cup down a bit and trim it while it is on the nozzle, which gives some support, or remove it entirely. Either way, don’t let the knife touch the nozzle itself. The yellow cap on the Cesaroni motor has a precut hole.

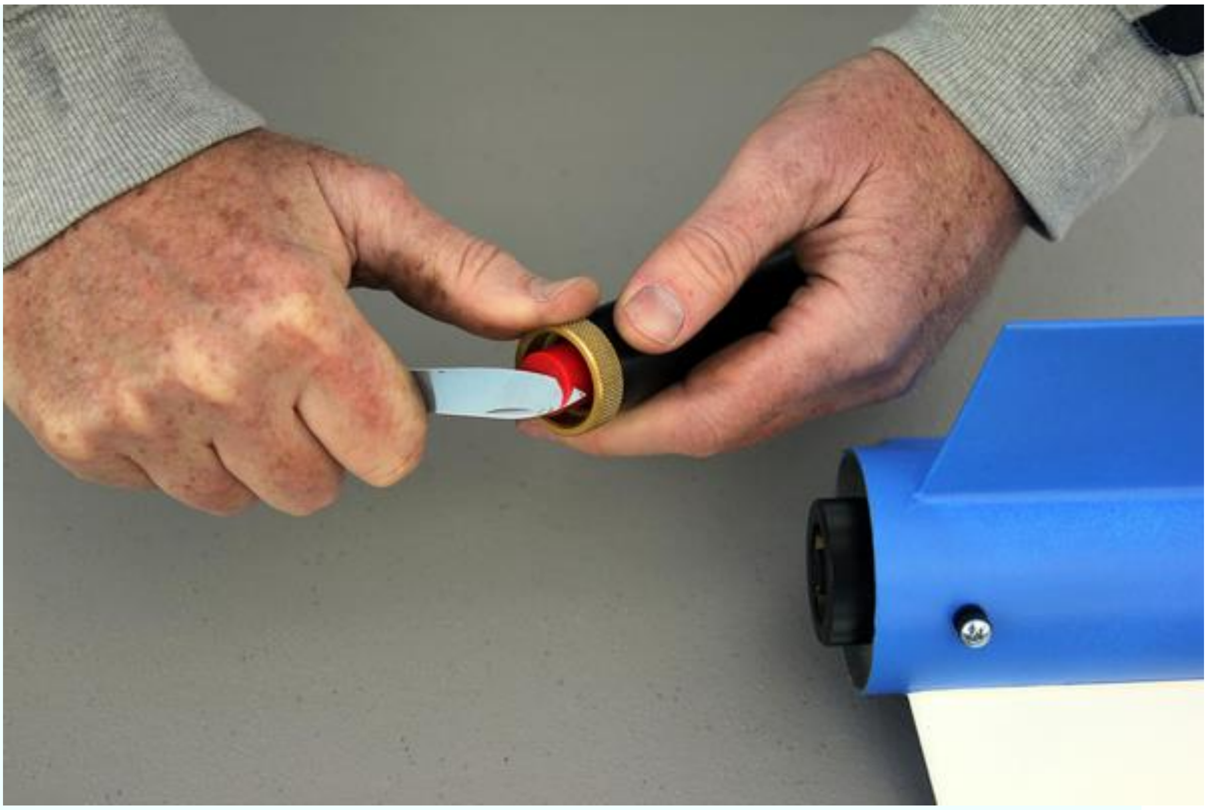


Figure 5-1. Cut a 1/16”- to 1/8”-wide hole in the plastic cup covering the nozzle.

Slide the motor into place. Don’t insert the igniter—the igniter is never put in a high-power rocket until the rocket is in launch position. Screw the retaining ring into place, tightening by hand (see Figure 5-2).

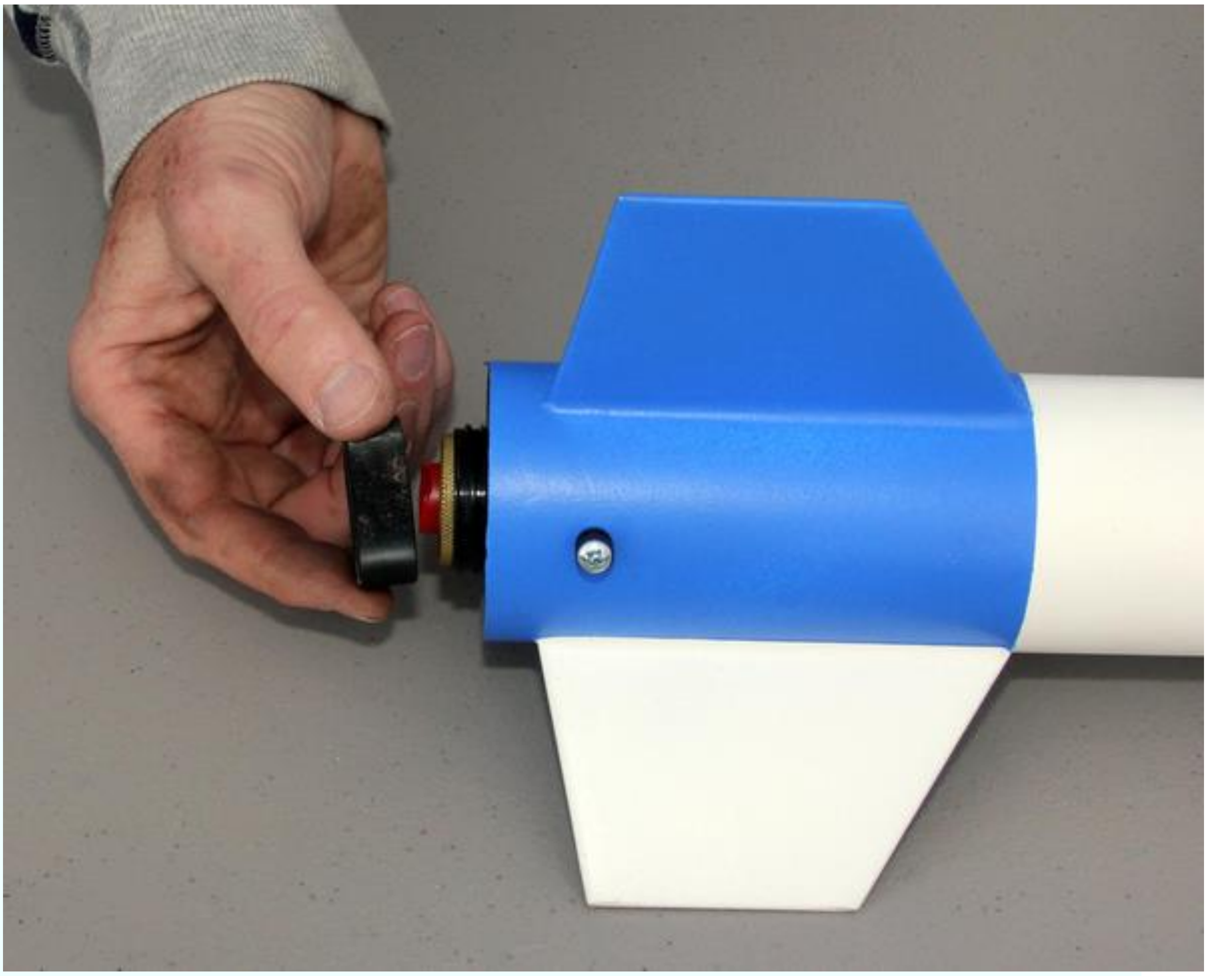


Figure 5-2. Insert the motor and screw on the retaining ring.

Lay the parachute out on a flat surface and fold it so all of the shroud lines are on the outside of the panels, as shown in Figure 5-3. If the parachute has six panels, you will be folding it in half, then in thirds. Fold the shroud lines neatly across the top parachute panel. Attach the parachute protector and parachute to the middle quick link on the shock cord and close the quick link.

As you can see by looking at Figure 5-3, this was not the first flight for this particular parachute protector!

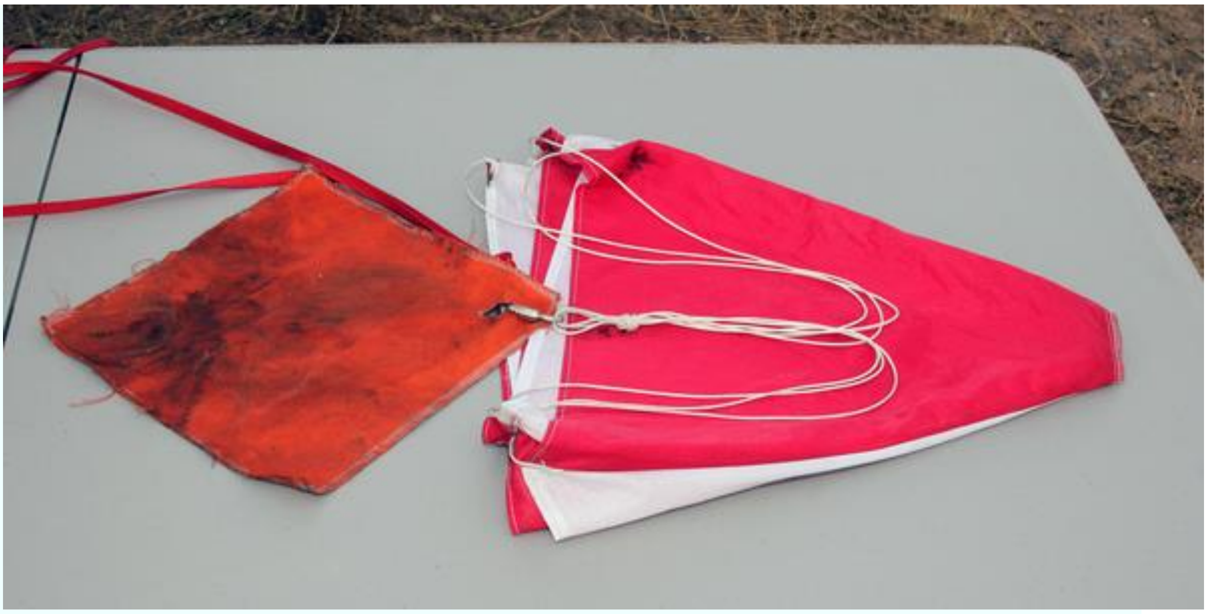


Figure 5-3. Fold the parachute and shroud lines. Connect the parachute protector, shock cord, and parachute using the middle quick link.

Continue to fold the parachute over the shroud lines until it is narrower than the body tube of the rocket, and then fold it in thirds. You may end up folding the parachute in halves or quarters if your parachute or chute protector is a different size. The idea is to get the parachute bundle smaller than the diagonal of the chute protector (see Figure 5-4).

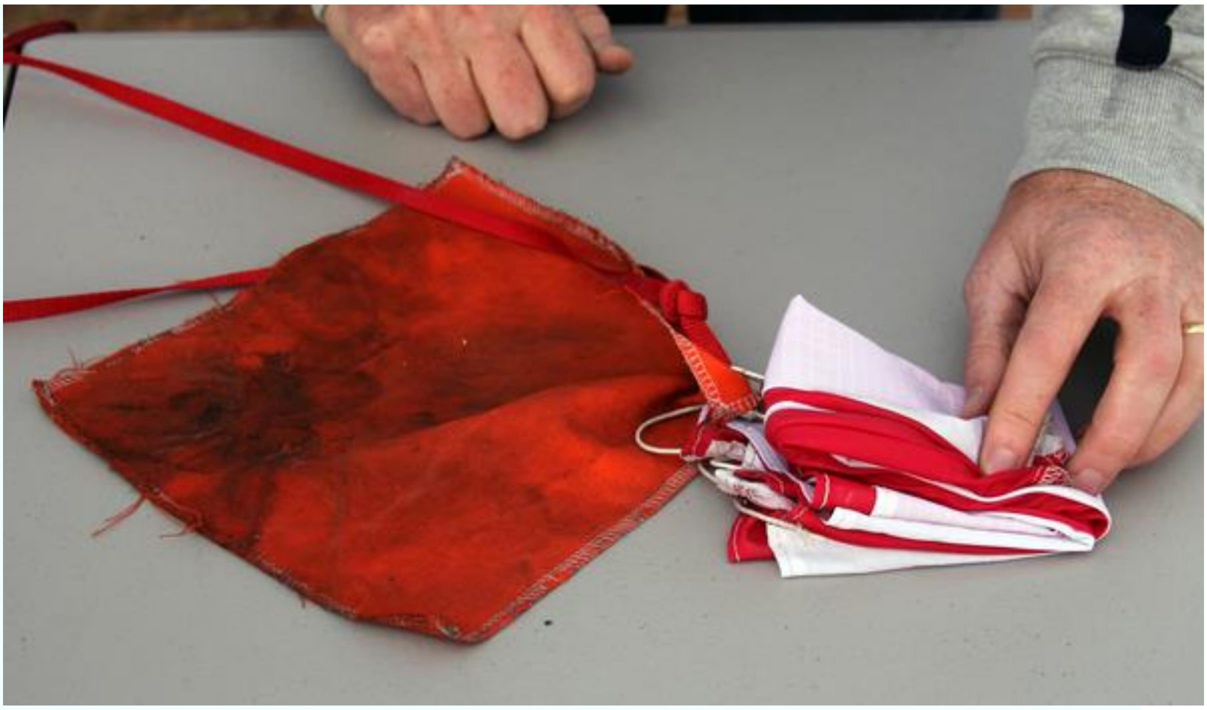


Figure 5-4. Fold the parachute until it is smaller than the diagonal of the chute protector.

It’s now time to learn a southwest rocket favorite—the burrito fold. Lay the parachute on the chute protector so the shroud lines are right next to the quick link. Fold the opposite corner of the chute protector across the parachute (see Figure 5-5).

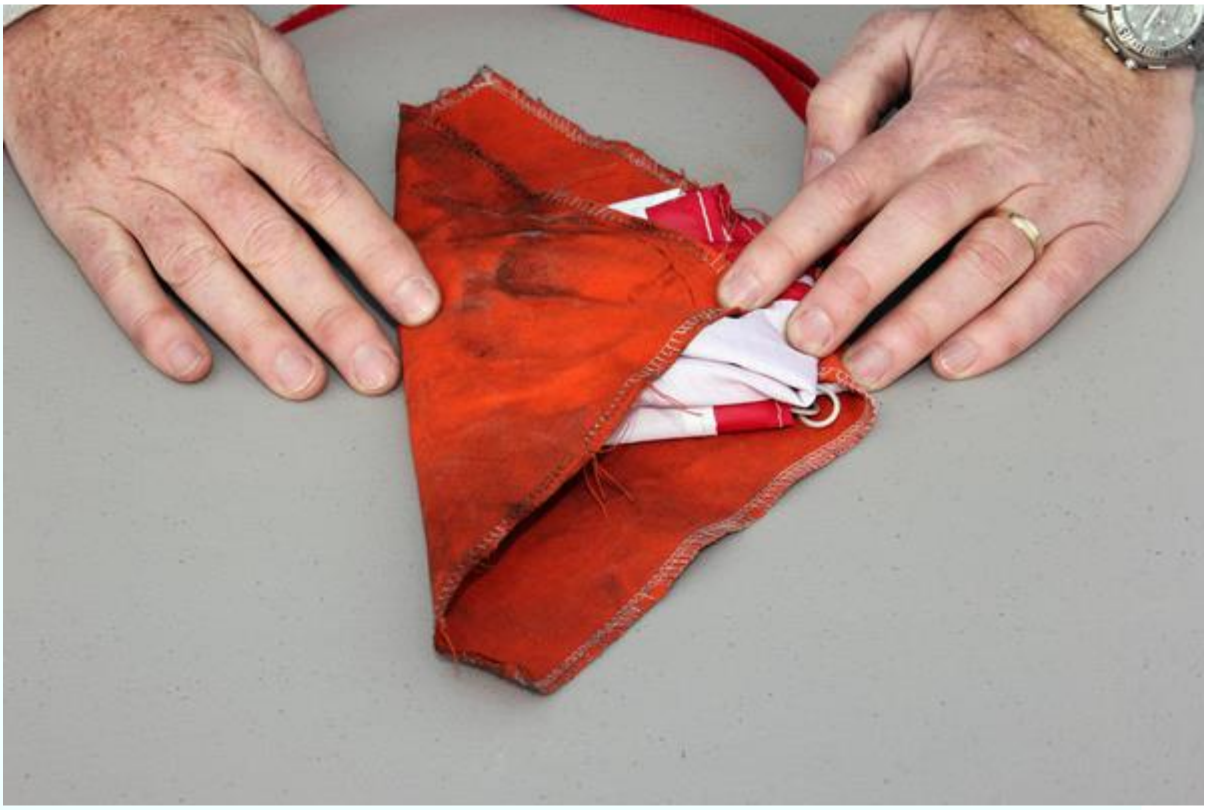


Figure 5-5. Place the parachute at the corner of the chute protector with the quick link, then fold the opposite corner across the parachute.

Wrap the parachute by folding one of the remaining corners across the parachute bundle (see Figure 5-6).

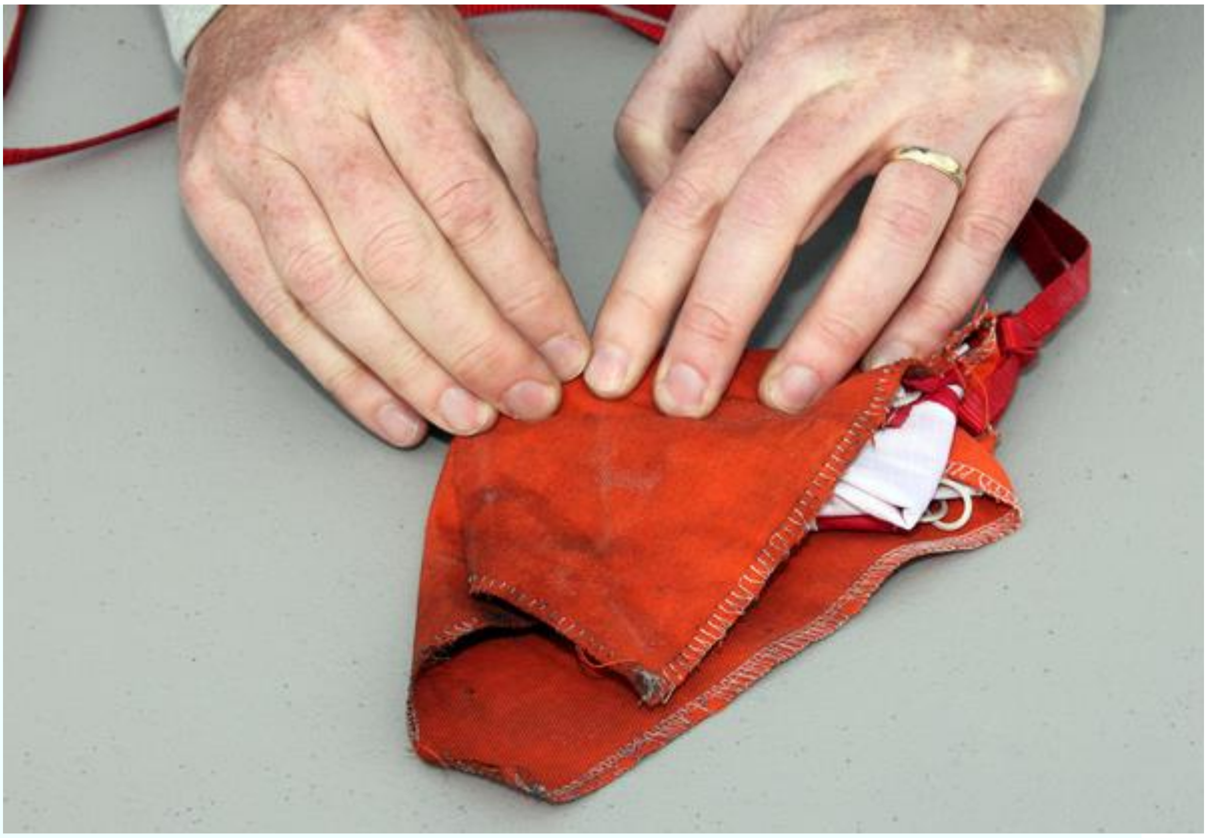


Figure 5-6. Fold one corner across the parachute bundle.

Tightly roll the parachute bundle toward the last corner. This will form a nice, neat package that completely wraps the parachute and shroud lines in the chute protector (see Figure 5-7). If any of the parachute or shroud lines stick out, refold the parachute and try again.

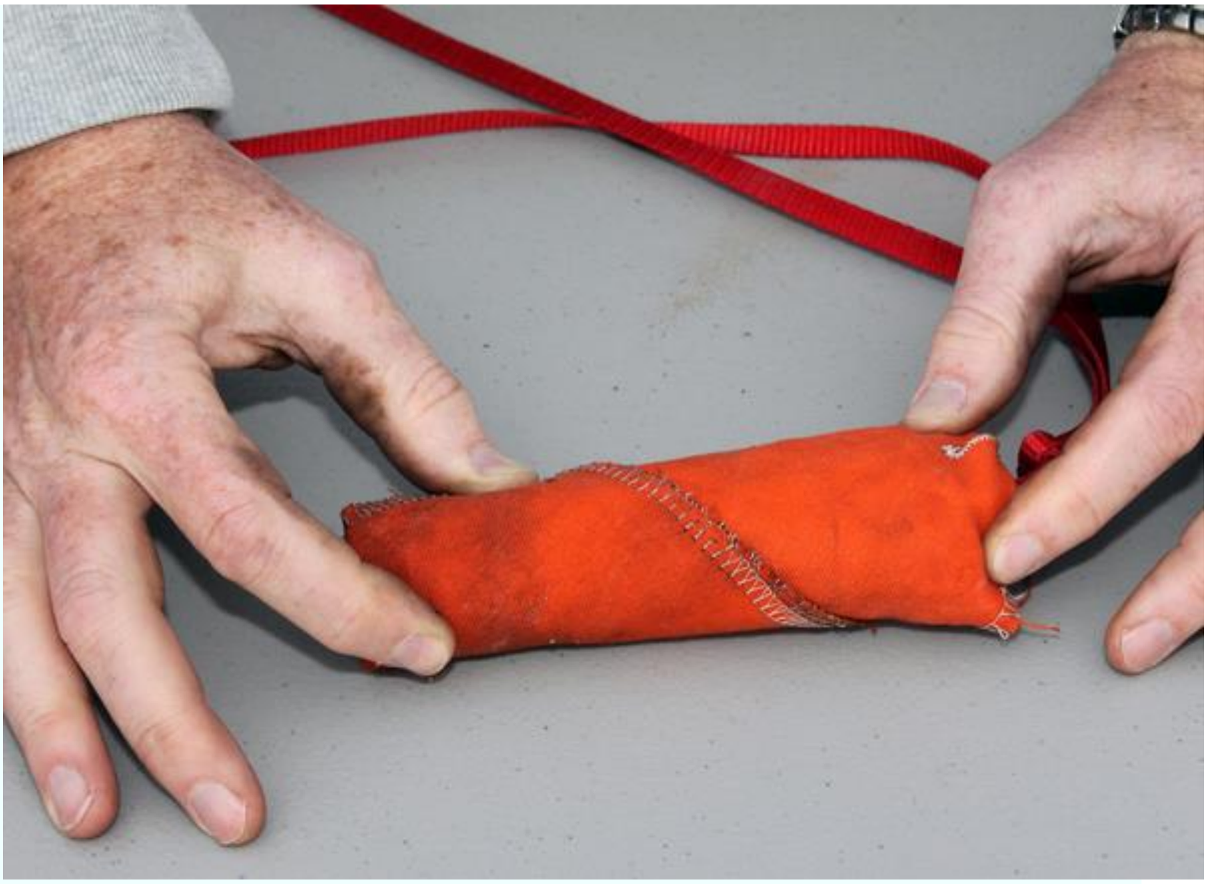


Figure 5-7. Roll the parachute to form a tight bundle that completely covers that parachute and shroud lines.

Pull as much of the shock cord out of the body tube as you can. Insert the bundle into the body tube of the rocket (see Figure 5-8). The chute protector will take the brunt of the blast from the ejection charge.

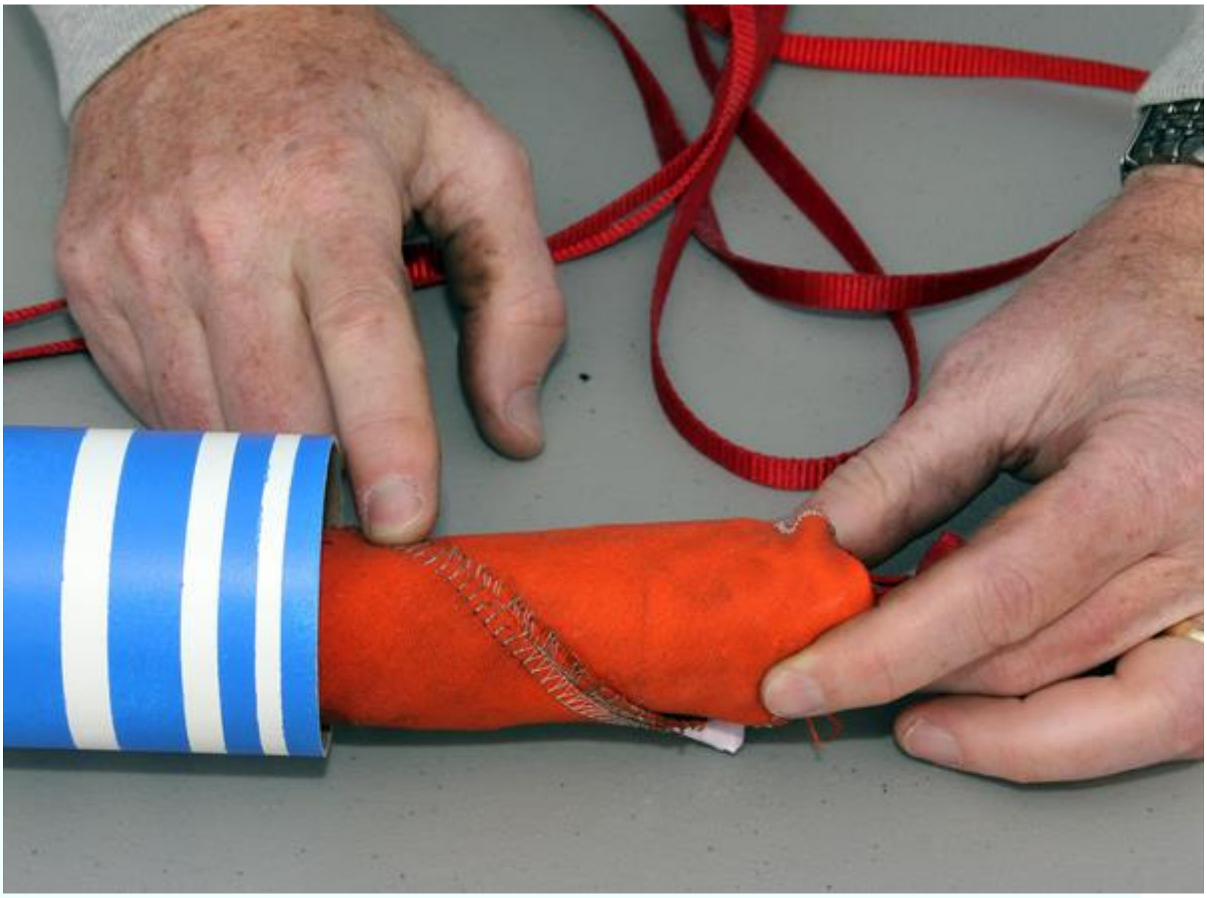


Figure 5-8. Insert the parachute bundle first.

Connect the quick link at the end of the shock cord to the payload bay and close the link.

Stuff the shock cord in after the parachute. Add the payload section (see Figure 5-9). Make sure the payload section can slide in and out of the body tube smoothly. It should be tight enough so it won’t fall out if you turn the rocket over and shake gently, but it should not be so tight that you have to push hard to get it in place.

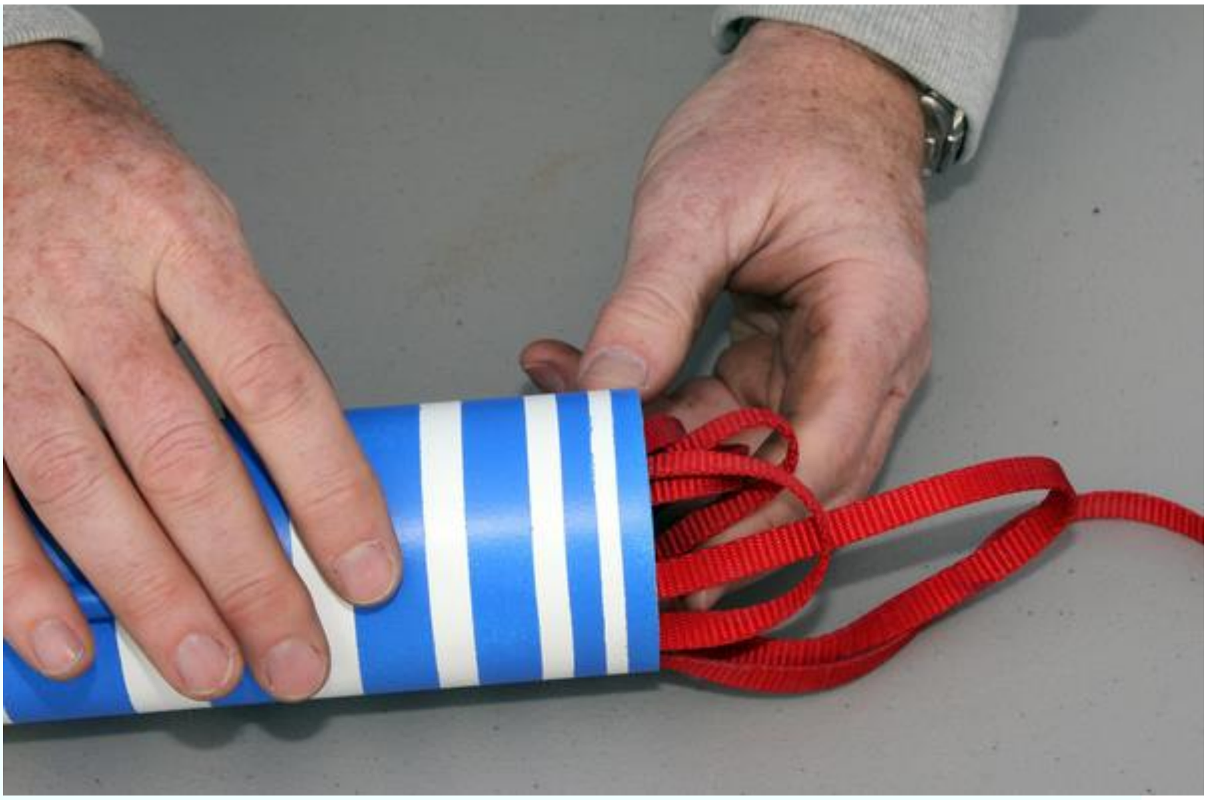


Figure 5-9. Put the shock cord in after the parachute. Seal the recovery system with the payload bay.

Tape the igniter to the side of the rocket. Depending on how the launch operations are performed, this may be the time to turn in your flight card and wait for a pad assignment. Once you have your pad assignment, gather the rocket, some tape, and your certification official and head out to the pad.

Once at the pad, slip the rocket into place on the launch rail or launch rod. The launcher may have a stop to keep the motor an inch or so away from the blast deflector place. If not, scour the local landscape for something to prop the rocket up a bit. I’ve used everything from a rock to a chunk of bone from a dead cow.

The next step is to insert the igniter. Before you do that, though, make sure the launch controller is in a safe mode. There should be no chance the launcher will fire the igniter while you are working. The LCO or one of the other fliers can answer any questions you have about the launcher, but this bears repeating: be absolutely sure the launcher is in safe mode. If you have the slightest shred of doubt, connect the igniter while it is outside of the motor to makes sure it does not light.

Remove the plastic cup from the nozzle. You might need pliers or the edge of a knife to get it off. Straighten the wires on the igniter. Strip a couple of inches of insulation and lightly twist the wires together a few turns. If a static charge builds up, this diverts it from going through the part of the igniter that lights the motor. Pull the wires though the hole in the plastic cup. Slip the igniter in all the way; it should touch the top of the front fuel grain (see Figure 5-10). Push the plastic cup into place.

Some people press the cap over the igniter, pinching the igniter in place against the nozzle. I generally stick it through the hole in the plastic cup and tap everything in place. Both methods work fine. Either way, though, if the igniter is still loose, add a piece of tape to the plastic cup to keep the igniter from dropping. It’s also perfectly acceptable to tape the igniter to the launch rail to remove strain on the igniter. Whatever method you use, make sure there is nothing that will pull the igniter out of place. Don’t worry about using too much tape. When the motor lights, it will have no trouble pushing the igniter, the cup, and any tape out of the way.

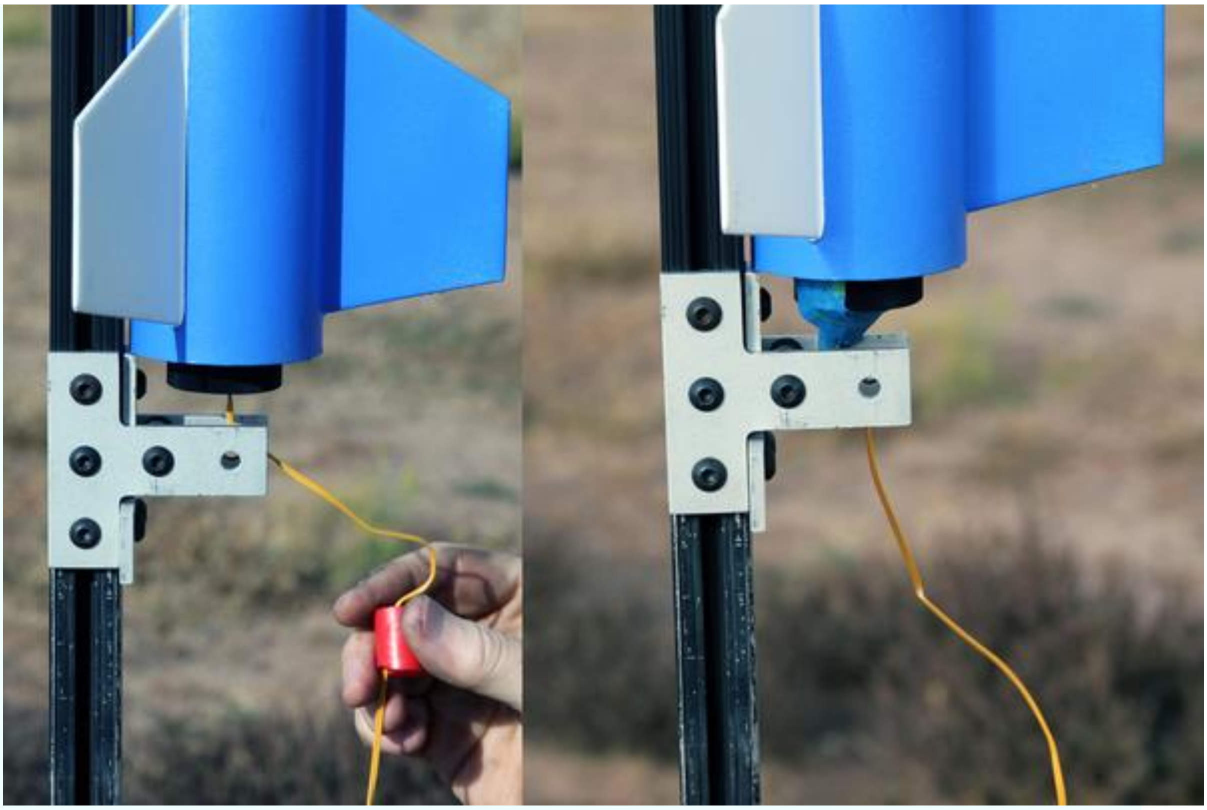


Figure 5-10. Insert the igniter all the way into the motor so the tip of the igniter touches the top end of the top fuel grain. Secure it with the plastic cup and tape so there is no strain on the igniter.

Insert the end of the igniter wire in the launch clip, and then wrap it around the clip up to the insulation (see Figure 5-11). Repeat for the other clip. Make sure the clips or the exposed wire don't touch each other or anything else made of metal. You can tape them out of the way to make sure they don' t touch when the wind blows the wires around.

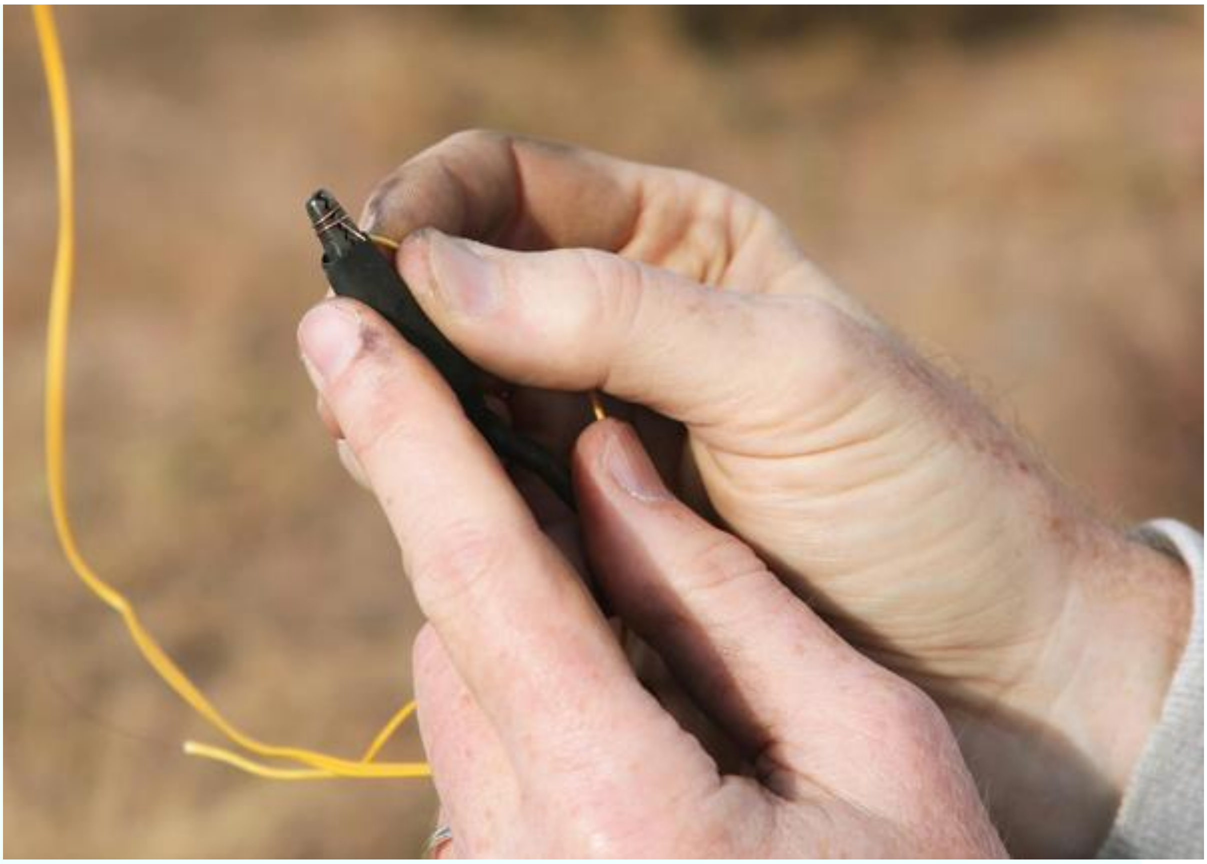


Figure 5-11. Attach the igniter clips.

The launcher probably has some way to test continuity, which verifies that all of the electrical connections are made. If so, test the continuity. Your rocket should be ready to launch!

Flight Preparation Checklist

1. Prepare the motor following the appropriate motor preparation checklist.

2. Cut a notch in the plastic cup that covers the nozzle if there isn’t one already.
3. Insert the motor and secure it with the motor retainer.
4. Attach the parachute and chute protector to the center quick link.
5. Fold the parachute and chute protector.
6. Attach the end of the shock cord to the payload bay with a quick link.
7. Insert the chute, then the shock cord.
8. Insert the payload bay, making sure it is snug but not tight.
9. Place the rocket on the pad.
10. Make sure the launcher is in safe mode.
11. Twist the bare ends of the igniter together.
12. Insert and secure the igniter.
13. Attach the igniter clips, making sure they do not touch.
14. Test for continuity.

The Flight

At this point, you’ve done everything you can for a successful flight. It’s time to enjoy the flight. Other than keeping a close eye on your rocket, there really isn’t anything else to do until just before the rocket lands.

You might push the launch button yourself. If so, make sure the LCO is ready. The LCO or someone familiar with the launcher will make sure it is ready for flight. This may include selecting the proper pad on a control panel, and will definitely involve inserting a launch key. Unless it’s a very small launch, you won’t do these tasks. Once you are told to proceed, count down from five. When you get to zero, press and hold the launch button.

Igniter Failure

Sometimes the igniter won’t launch the rocket. Perhaps there was a short or a problem with the launcher, and the ingiter is still usable. Perhaps the igniter lit, but did not ignite the rocket fuel. It happens.

Always wait 60 seconds before approaching the rocket after an igniter failure. I’ve seen rockets, especially high-power ones, take a long time to light. They sometimes sit for 10 seconds or more before suddenly jumping off of the pad. You don’t want to be walking up to the rocket when that happens.

Get an experienced flier to take a look at your igniter installation. Make sure it is pushed all the way up in the rocket motor and secured so it won’t drop out, even under the weight of the clip.

Sometimes, though, you do everything right and the rocket just doesn’t lift off. Swap the igniter for a spare and try again.

You might want to take pictures, too. That’s understandable. However, I recommend leaving the launcher and picture taking to someone else. In fact, stand back a bit. You will see the flight a lot better if you back up from the pad.

While all eyes will be on your flight, no one will be more interested than you are in where the rocket lands. You should take a very careful sight line just as the rocket touches down. This should be as specific as possible. In Figure 5-12, for example, “to the right of the water tower” is not good enough. You need to be thinking, “toward the second high-power tower to the right of the water tower.” Once the rocket lands, pick out a landmark on a direct line toward the landing spot and walk to that landmark. Perhaps it’s a distinctive bush. Once you are there, pick out a new landmark and walk to it. As you go, check the terrain in front of you, to the sides, and even behind. I’ve walked right past a rocket because it was hidden from view in one direction.

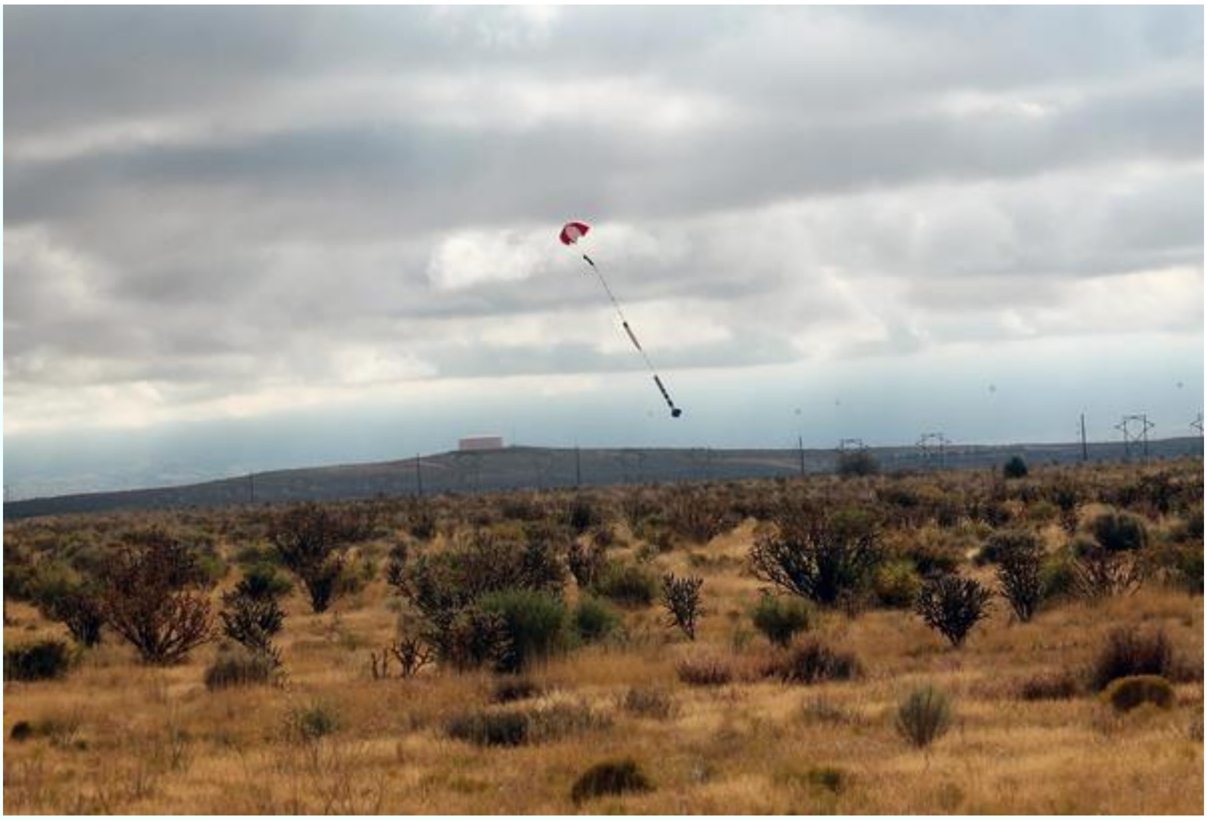


Figure 5-12. Just as the rocket lands, pick out a landmark far in the distance. Walk toward the landmark to find the rocket.

Once you find your rocket, collect it and bring it back to your Level 1 certification official for inspection. They will inspect the rocket and, assuming everything went well, sign your certification paperwork. You can mail the completed form to the address on the form, fax it, or scan the form and email it. Whatever you do, be sure to keep a copy for yourself.

Cleaning the Motors

Rocket fuel is corrosive, and can damage the rocket motor if you don’t clean the motor fairly quickly. It’s not something you need to do right after you recover the rocket, although you certainly can do it then if the motor is cool enough. You should plan to clean the rocket the same day as the flight if at all possible, or at the very least no later than the following day.

Of course, you don’t have anything to clean if you are using an AeroTech single-use motor, and there isn’t much to clean with the Cesaroni motor. For the Cesaroni motor, unscrew the aft retainer, pull the reload out, and drop it in the trash. Follow the procedures below to clean the case and aft retainer.

Cleaning an AeroTech reloadable motor is not hard, but it is a little more involved than cleaning a Cesaroni motor. Let’s step though cleaning the motor to see how it is done.

You will need a few supplies (shown in Figure 5-13). You can use paper towels and rubbing alcohol to clean a motor, but I prefer using baby wipes. They come in a nice convenient package, they are presoaked with a cleaner, and they work really well. You may also need pliers to pull out stubborn parts and a pencil or other soft stick to push out the motor liner. Once you finish cleaning the motor, you will also need some light grease.

Remove the front and aft seals and set them aside. Push the motor liner and any seals or O-rings out of the motor case (see Figure 5-14). They may be loose enough to push out with your finger, or you may need to use a wooden stick. Don’t use anything metal; you don’t want to score the inside of the motor tube.

Figure 5-13. Cleaning supplies include paper towels and rubbing alcohol, baby wipes, pliers, and a pencil or wooden stick.

Pull the delay assembly from the forward retainer (see Figure 5-15). It may be loose enough to shake out, but more often it is a little snug. Use pliers if you need to, but be careful not to damage the forward closure with metal tools. Don't forget the O-ring. It may slip off of the delay element. There is also a delay spacer that will stay lodged against the forward end of the closure. Remove these with your fingernail or a soft, nonmetallic tool.

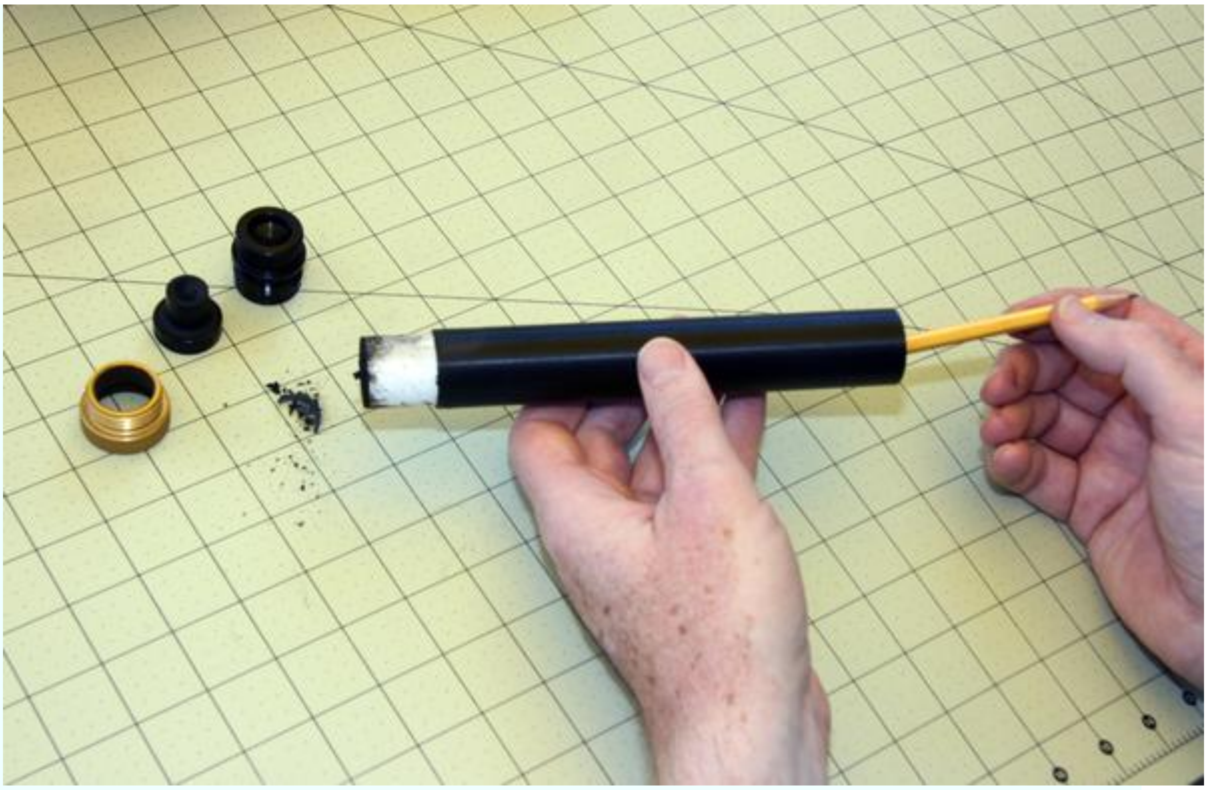


Figure 5-14. Push out the motor liner.

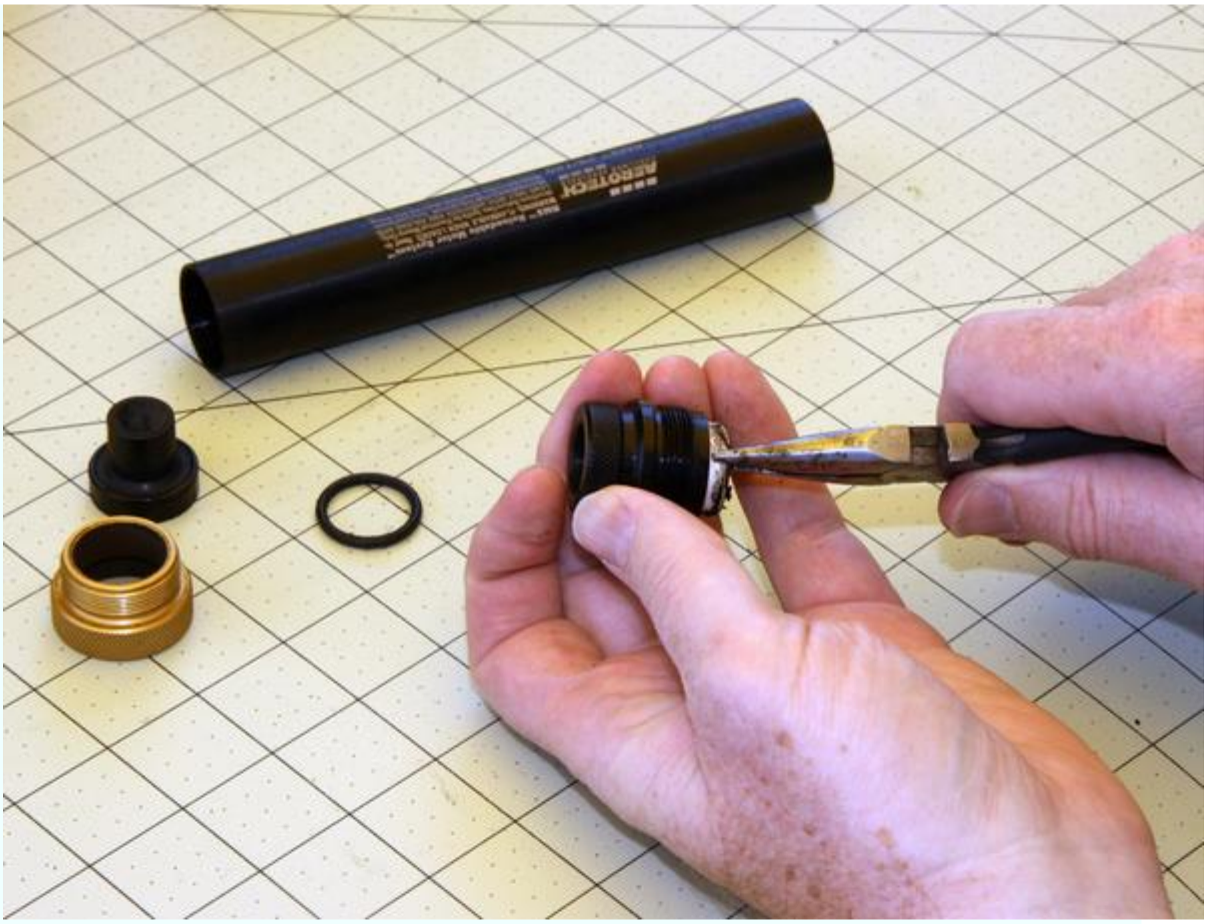


Figure 5-15. Remove the delay assembly from the forward closure.

Clean the inside and outside of all parts thoroughly with wipes or a paper towel soaked in rubbing alcohol (see Figure 5-16).

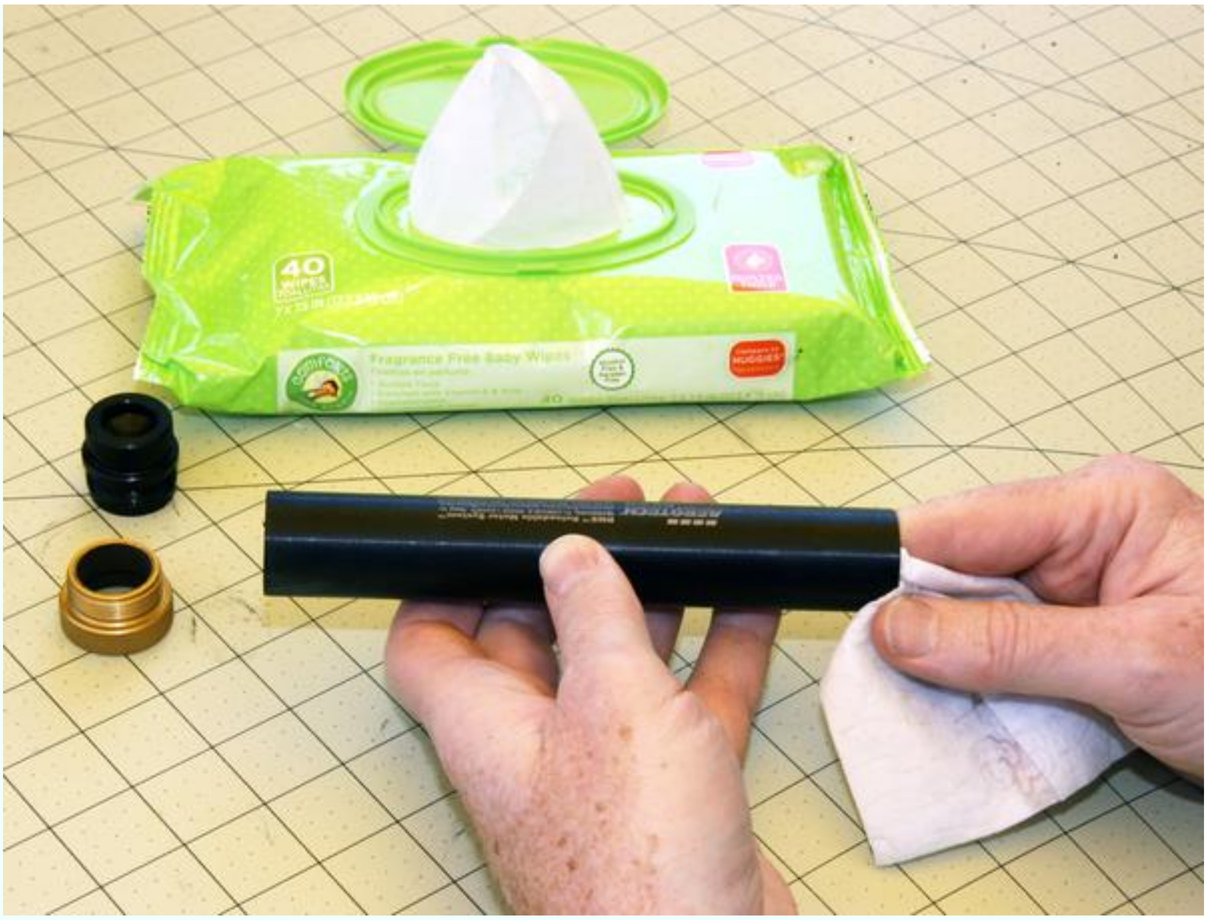


Figure 5-16. Clean the parts of all residue.

Take extra care with threads. Push a wipe into the thread with your fingernail and run it along the thread like you are unscrewing the part (see Figure 5-17). Keep doing this until the wipe is clean after a complete pass through the thread groove. Don’t forget the threads on the inside of the motor case.

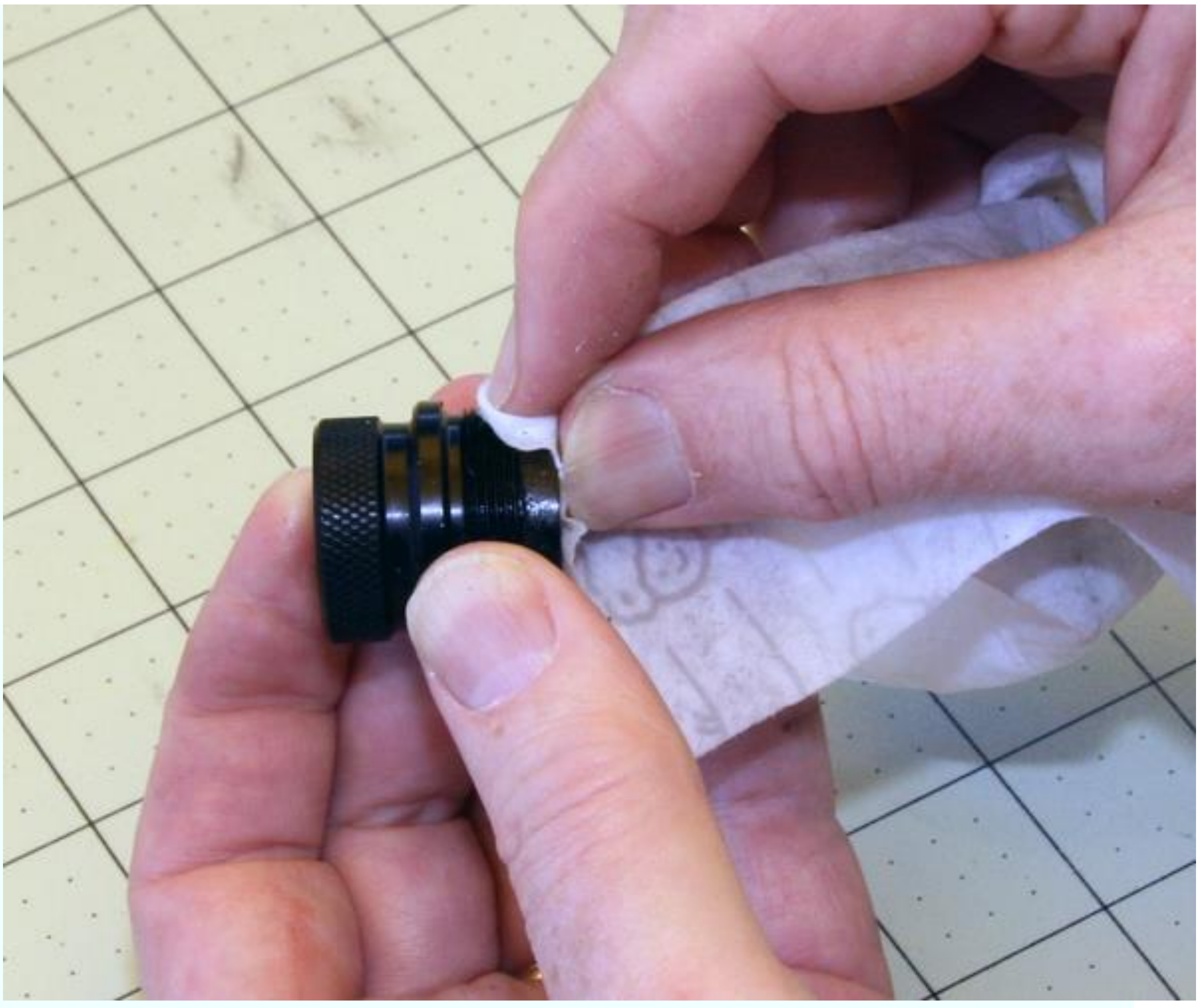


Figure 5-17. Clean threads by pressing a wipe into the thread groove and turning the part like you are unscrewing it.

When you are finished, the motor case and closures should not have any visible residue from the rocket fuel or ejection charge. Throw away all of the parts from the reload and the used wipes. They are safe to toss out with the household garbage, but you might want to put them outside right away, since they do have a distinctive smell.

Once the motor is clean, put a small amount of light grease on the threads and screw the closures lightly into place. Store the motors in a place where they will not have weight on them. I wrap mine in bubble wrap and label the contents.

Disposing of a Motor or Ejection Charge Material

You might occasionally end up with a motor you need to dispose of for some reason. My favorite way to dispose of a motor is to fly it, but perhaps youammonium perchlorate composite propellant (APCP) have a motor with some damaged components, or a motor reload without a matching case. Whatever the reason, let’s assume you have a motor you need to dispose of. There are three ways to do this, depending on the situation.

Most of the motors in high-power rocketry use ammonium perchlorate propellant, but there are a few that use black powder. If your motor happens to use black powder, soak it thoroughly in water. Once it has soaked, toss the remains out with the normal trash.

If you need to dispose of an ammonium perchlorate–based high-power motor, and you have a motor case and all of the parts, bury the fully assembled motor pointed straight down with just the nozzle exposed. Make sure there are no flammable materials, buildings, or animals within a radius that corresponds to the safe launch distance for the motor. Safe launch distances are listed in Table 5-1. Ignite the motor with a standard electric igniter. Give it time to cool afterward, and then clean the remains in the normal way.

If the motor or reload is damaged, burning the damaged parts in a rocket motor case is not a good idea. Leaving aside the fact that it might ruin the motor case, you could also blow the aft retainer, potentially ejecting burning fuel pellets like a Roman candle. The best way to dispose of loose rocket fuel is to dig a hole in the ground, place the motor grains and smoke charge into the hole, and then light the fuel with a standard igniter. It won’t explode, but it will burn quickly and with a great deal of heat, so keep the area around the hole clear of flammable material or animals for a distance of several feet. Douse any remains with water, then bury them or scoop them out (when they’re cool) and dispose of them with the household trash.

The ejection charge is black powder. You can dispose of it by soaking it in water, then throwing it out with the trash. The delay charge can be disposed of by burning when you burn the fuel. All other motor parts are inert, so toss them out with the trash.

Occasionally there are local regulations that might prevent you from lighting a fire of any kind outdoors, especially one fueled by rocket motor grains. Check with the fire department if there is any doubt.

Use water to put out any fire involving rocket fuel. Rocket fuel contains its own oxidizer, so CO_2 or foam fire extinguishers won’t work. They are designed to smother a fire, robbing it of its oxygen. Water puts out a fire by cooling the material. Be sure to keep a bucket of water or a hose handy when you are burning rocket fuel, whether in a motor or a pit.

Chapter 6. The Level 2 Rocket

Level 2 rockets are designed to use J, K, or L motors, although they frequently can use larger or smaller motors, too. This chapter shows you how to build two of them. The first, Deimos, is shown in Figure 6-1.

Figure 6-1. Deimos is a fine flier that can soar a mile high on a small J motor. Here it lifts off on an AeroTech J350W.

There are several reasons for presenting two Level 2 rockets instead of one. Deimos, which is made from a kind of plastic body tube called Quantum tubing sold by Public Missiles Ltd., is light enough to fly with large G motors, so you can use it for your Level 1 certification as well as your Level 2 certification. Although it can fly on small motors, Deimos can also handle large J motors. You will learn how to work with plastic structural parts while building this rocket.

It’s hard to tell the difference between Phobos, our second Level 2 rocket, and Deimos just by looking at them. The body tubes and fins are the same size, and the nose cones are almost a match. The difference is that Phobos is built from fiberglass. Deimos uses 38 mm motors, while Phobos uses 54 mm motors. Phobos is heavier, so you should use at least an I motor, but it can handle K motors. It can easily break the sound barrier, and flies to around 10,000 feet. Still, because of its weight, you can fly Phobos using a J motor and keep the flight under 4,000 feet. That’s a big advantage in areas where higher clearances are hard to get. Phobos also gives you experience working with fiberglass, which is used in a lot of very high-performance rockets.

This chapter will show you the basic construction techniques. You can fly the finished rockets just as you did Callisto, but you probably won’t want to fly them for your Level 2 flight without modifications. That’s because these rockets can go really high! You risk losing the rocket or busting the FAA clearance if you fly either of these rockets with a parachute that opens at apogee. Remember, the FAA clearance is not just for an altitude (although that’s what we usually list); it also describes a specific safe radius around the launch site. A rocket that opens a large parachute at apogee might drift outside the designated flight area.

Both rockets are easy to adapt for dual deployment, in which a small drogue parachute deploys at apogee to slow the rocket down slightly, while still dropping it fast enough to keep it from drifting too far. After the drogue stabilizes the descent, the rocket deploys a large main parachute at about 1,000 feet to slow it for landing.

We'll look at two methods for dual deployment. One, using cable cutters, works with either of the rockets in this chapter. We'll look at cable cutters in Chapter 7. The other common way to handle dual deployment is with two separate parachute bays, a method we'll see in Chapter 8. You build the rocket slightly differently for this recovery method. Since you will find reasons to use both recovery methods on other rockets, I suggest experimenting with both of them using Deimos or Phobos. You can build either rocket for both the cable cutter and drogue–main configuration and get experience flying both ways.

Even with dual deployment, it's a good idea to have some way to track your rocket. There are a lot of different ways to do this, from radio direction finders to GPS units to light-activated whistles. These are covered in Chapter 10. All of these variables mean your rocket could weigh significantly more or less than the rockets in this chapter, too, so you need to know how to pick the right size parachute, a topic we cover in Chapter 9.

Taken together, this means you should not start building either rocket before reading a bit further in the book. You should read through at least Chapter 10 before ordering parts for your Level 2 rocket. I'd suggest starting with Deimos using a cable cutter or dual parachute bays, along with some form of tracker, for your Level 2 flight.

Deimos: A Plastic Level 2 Rocket

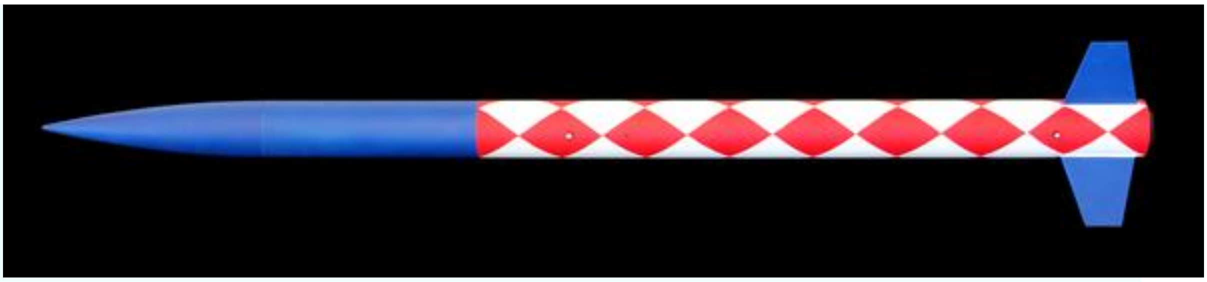


Figure 6-2. Deimos is an impressive 3"-diameter, 5-foot-long rocket that is perfect for a Level 1 or 2 certification flight.

Deimos

This rocket (Figure 6-2) is named for the outermost moon of Mars. It is similar to an asteroid in size and composition, but its circular orbit on the equatorial plane of Mars suggests it formed by accretion as Mars formed.

There is still a lot of discussion about which way the little moon actually was created.

Deimos and Phobos, Mars’s other moon, are twins in Greek mythology and very similar as moons, making these names great choices for two very similar Level 2 rockets.

There are several really good rocket companies around. We used parts from LOC Precision for our Level 1 rocket because LOC Precision is known for using safer, inexpensive paper tubes for its rockets. You could, in fact, build Deimos with LOC Precision parts. It’s nice to explore alternatives as you get started, though. For this rocket, I’m recommending parts from Public Missiles Ltd., better known as PML. PML is famous for its Quantum body tubes, a trade name for a plastic tube that is well suited for building rockets. The part numbers in Table 6-1 are all PML part numbers. The parts listed here are shown for reference in Figure 6-3.

Part	**Description**
Nose cone	The nose cone for the rocket. PML sells a 3”-diameter, 13.25”-lon nose cone.
Booster airframe, 3”-diameter, 36” long	This is the 3”-diameter Quantum tubing, sold in 36” lengths. We’l the full length of the tube for the booster airframe.
Payload airframe, 3” diameter, 12” long	We will cut a second piece of Quantum tubing that we will cut for payload bay. There is enough extra tubing to build the second configuration of the rocket that uses two parachute bays, but there few other parts you will need to add. See Chapter 8 for the comple parts list for the alternative version of the rocket. You can also bu PSK-3.0x12-QT, which has just the right amount of tubing and co with an eye bolt, bulkhead, washer, and bolts.
Tube coupler, 5” long	PML sells this three ways. You can get the tube coupler and other as part of a payload bay kit, you can buy 5” of tube coupler precut you can buy a 36” length and cut your own. The catalog number l here is for the precut tube coupler.

Part	Description
Bulkhead	This bulk plate forms the base of the payload bay.
Eye bolts (2)	One eye bolt is attached to the bulk plate, and used to attach the sh cord that holds the booster to the payload bay. The other is mount the forward centering ring. This is where the other end of the shoc cord will attach.
Washer	The weak point in the recovery chain is the bolt sticking through t plywood bulk plate. The washer spreads any force over a wider ar the wood, lowering the chance a sharp pull will yank the eye bolt through the bulk plate.
Nut for eye bolt	The nut for the eye bolt, sold separately by PML.
Fins (3)	PML sells precut fiberglass fins in a variety of shapes and sizes, a offers a cutting service for custom fins. You can certainly use plywood fins instead, but fiberglass fins are stronger, and since they can be much thinner, they have lower dra
38 mm motor tube, 12”	PML sells phenolic tubes, which are thick paper and resin tubes. T are very much like the motor mount tubes used for Callisto. These widely used for motor mounts, although they can also be used for airframes. The tube is 36” long, and will need to be cut.
Centering rings (2)	Two centering rings hold the motor tube in the airframe.
Motor retainer	This is a two-part motor retainer like the one used in Callisto, but bigger.
Rail buttons (2)	PML sells a linear launch lug that glues directly to the body tube, you can order standard rail buttons from another company. The ca number is for the PML linear launch lug.
Nuts for rail buttons (2)	You can buy these or make them from 1/8” x 3/4” aluminum stoc we did for Callisto. The linear launch lugs don’t need nuts, although you can use them

Part	**Description**
	you like. The construction details show standard rail buttons with aluminum nuts.
Quick links (2)	Get larger quick links rated for at least 800 pounds for this rocket.
Tubular nylon	PML sells a wide variety of shock cord. I recommend 9/16”-wide tubular nylon for this rocket. You can get that directly from PML order a larger amount from a company that specializes in nylon. Y will need 20 feet for the rocket as built in this chapter, and anothe feet if you convert it for dual parachute bays, as seen in Chapter 8 See “Building Deimos” for a discussion.
Nomex tubing	We will use a bit more black powder in this rocket. You can use a variety of shock cord protectors. We saw one from LOC Precision the Level 1 rocket, and it will work fine here, too. The text shows alternative, which is Nomex tubing. See the text for thoughts on ordering.
Parachute	As designed, this rocket does well on a 48” parachute. You may e modifying the rocket enough that it needs a different size, though. See Chapter 9for ways to find the proper size.
#4 1/2”-long pan head screws (3)	These will be used to secure the nose cone. You can find them at t local hardware store, or order a box online.

Table 6-1. Parts list for Deimos

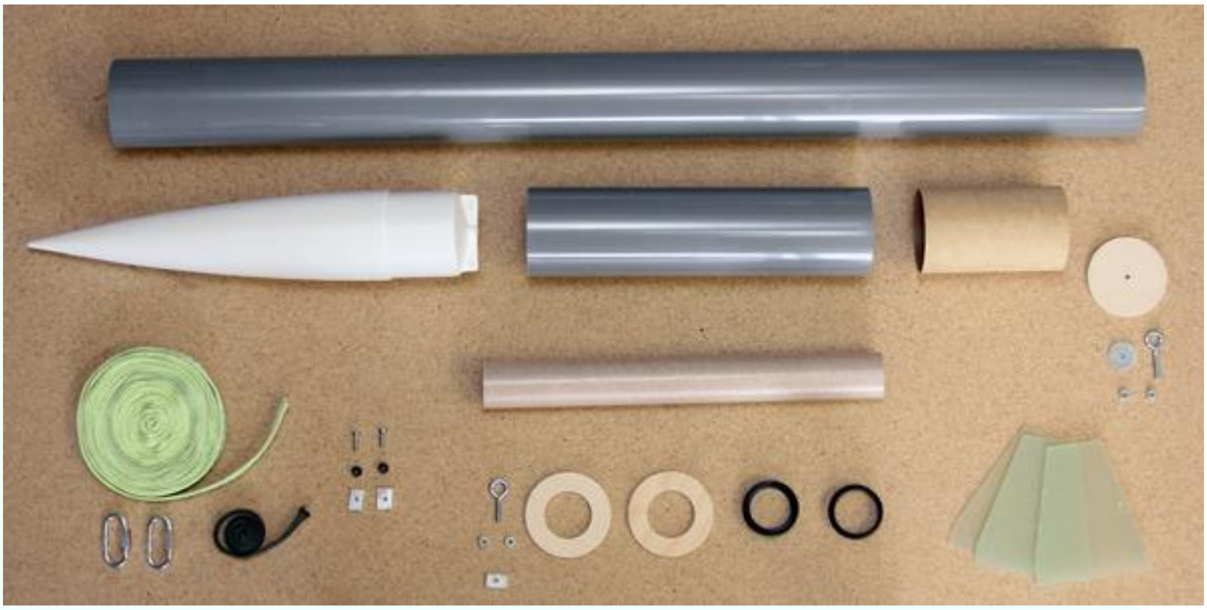


Figure 6-3. Visual parts list. The parachute is not shown.

For the most part, Deimos is built the same way as Callisto from Chapter 2. You will use the same tools and techniques. We'll experiment with a new way to attach the shock cord to the booster, try a new way of protecting the shock cord from the ejection charge, and use some new materials for construction, but these are fairly minor changes. Refer to Chapter 2 if you need a refresher on any tools or techniques.

Deimos Simulation Files

You can find the simulation files for Deimos at on my website, or you can follow the same methods from Chapter 2 and build your own. If you want to build your own simulation files, you will need to read through the construction details to figure out what all of the components are and where they go, but that's pretty good practice.

As you know from creating Callisto, the rocket you build with the simulator will not be identical to the actual rocket you put together. This stems from minor differences between the mass of the simulated parts and the mass of the actual parts, glue, paint, and various small things we don't take into account in the simulation, like screws. Without a motor, the simulated version of Deimos has a weight of 41.8 oz and a center of gravity 35.1" from the tip of the nose cone. My rocket weighs 49.7 oz with a center of gravity 35.5" from the tip of the nose cone. The difference is not huge, and doesn't affect the safety of the rocket, but it’s still worth correcting for the differences. I added a 7.9 oz mass component 12” from the front of the main airframe tube in the simulator to account for the extra weight and to shift the center of gravity to the actual location. That’s a good start, but be sure to do your own correction once your rocket is built.

Table 6-2 shows the simulated results for flying this rocket on some common motors. The CTI H163 or the AeroTech H128 are both great choices for a Level 1 certification flight or a sport flight. The AeroTech I218 lifts the rocket to about 2,600 feet. That’s a bit high for a rocket that does not use dual deploy, so I’d recommend holding off on using that motor until you add one of the dual-deploy mechanisms we’ll look at later in the book. You could fly the rocket with an I motor on a calm day and get away with it, but why risk it?

Motor	**Apogee (ft)**	**Max. velocity (ft/s)**
AeroTech G64-4	674	188
AeroTech H128W-6	1,057	267
CTI H163-9	1,230	308
AeroTech I218R-10	2.629	526
CTI J285-12	4,825	879
AeroTech J350-14	4,990	943

Table 6-2. Deimos simulation results

The AeroTech J350 and the CTI J285 are both great motors for a Level 2 certification flight. They will both carry the rocket nearly a mile high, though. I definitely don’t recommend flying the rocket on either of those motors unless you add dual deploy and a tracker of some kind. All of the rockets in this book have been tested using a representative sample of the recommended motors, so you can be sure they will work correctly and safely. I did fly this rocket using a 48” parachute ejected at apogee on a J285. The comment from one of the more experienced members of the club reflected the gentle critique common when one rocketeer has some reservations about the actions of another: “That was stupid.” Indeed, I would not recommend you do the same. I had a radio tracker in the rocket, which is the only reason I found it. It was a nice day for a walk, which is a good thing, because after driving as close as I could I still walked over an hour to recover the rocket. (The long walk was due more to the terrain than the distance.)

Building Deimos

Deimos uses three fins cut from 1/16”-thick G10 fiberglass. The easiest way to cut the fins is to let PML do it for you. The website lists a large number of stock fin shapes, and PML also has a service for cutting custom fins. I used FIN-A-02 for both Deimos and Phobos. You need to specify the size of the fin tang in the comments section of your order. You can reduce the chance of a mistake by simply telling them you are using QT-3.0 airframe tubing and PT-1.5 phenolic tubing for the motor mount. If you decide to do the calculation yourself, remember that the fin fits on the outside of the motor mount, but the tang extends through the outer airframe. The correct tang length is 0.7485”. Of course, if you are ordering fins for Phobos at the same time as you order fins for Deimos, be sure to order those fins for the larger motor mount we will use on that rocket.

If you prefer to do it yourself, you can cut your own fins from 1/16”-thick G10 fiberglass. Look ahead to“Cutting Fiberglass” if you decide to cut your own fins, though. PML is one of several sources for G10 fiberglass. You can also substitute 3/16”-thick aircraft plywood.

One of the planned projects for *Make: Advanced High-Power Rockets* is to convert Deimos and Phobos into a two-stage rocket, with Deimos as the second stage. With that in mind, we need to make a slight modification in the design of the motor mount to accommodate a forked tube coupler that will hold the two parts together. We’ll move the aft centering ring from its normal position (just ahead of the motor retainer) to a position 3 1/2” from the base of the rocket. That means the aft centering ring will cut right through the fins. So, you need to cut a 1/4” slot in each of the three fins. This is a little thicker than the centering rings, which are 3/16” thick. The extra 1/16” gives you a bit of spare room when positioning the centering ring, something you will appreciate later when you're trying to fit three fins and a centering ring into position before the epoxy glue sets! Cut the slot 3" from one end of each fin. The final dimensions for each fin are shown in Figure 6-4.

Make a fin template from corrugated cardboard or a similar material. This template should allow for the three 1/16"-thick fins that will protrude 4" from the body tube (see Figure 6-5). A 12" square of cardboard is just about right, but a little bigger doesn't hurt. The body tube is 3.002" in diameter; a central hole of 3" is close enough.

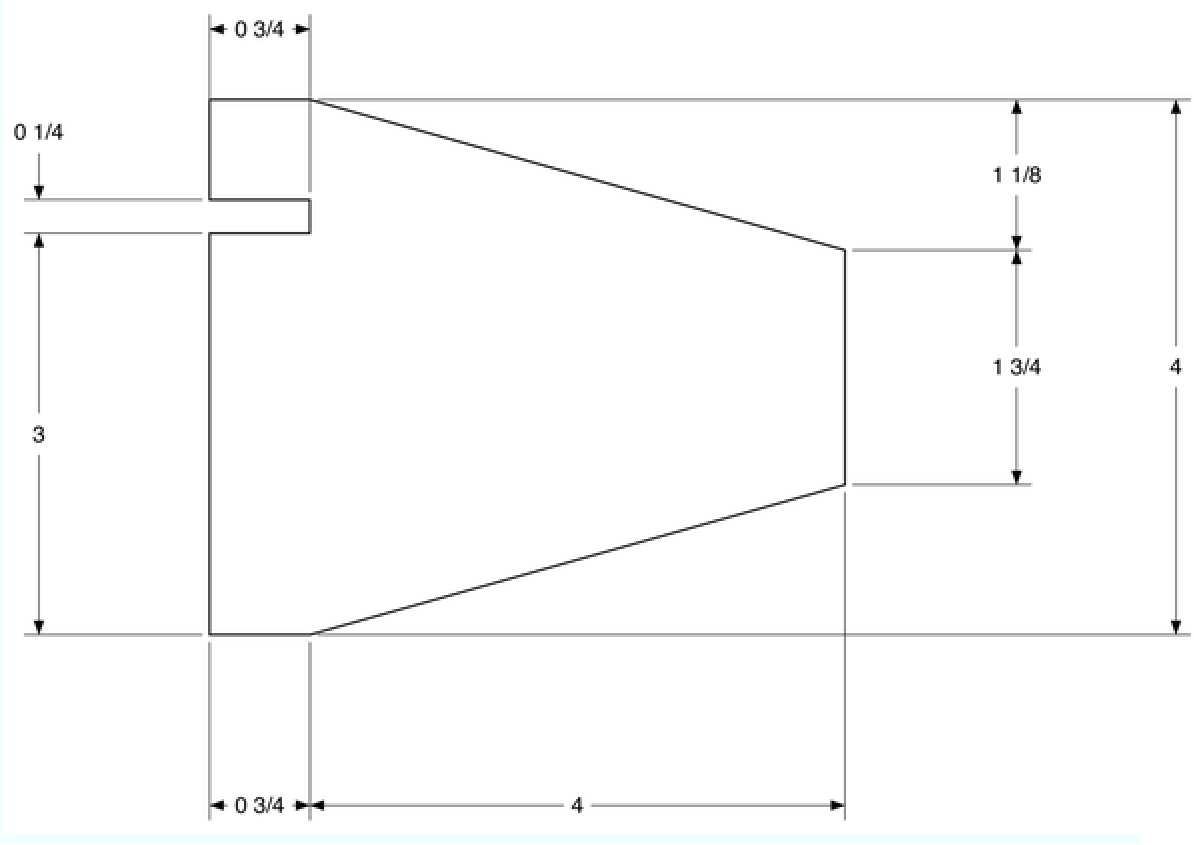


Figure 6-4. Cut three fins from 1/16" G10 fiberglass. You can order precut fins from PML, in which case you will just need to cut the slot in the tang.

The main airframe for the rocket is a 36"-long, 3.002"-diameter Quantum tube from PML. This tube is smooth, rigid plastic. It is easy to work with, easy to paint, and fairly rugged. It is sold in 36" lengths, and the main airframe for Deimos is 36" long, so you won't need to cut it to length.

Use the template to mark the locations of the three fins on one end of the body tube. You will need two marks for each fin, spaced 1/16" apart. Add a line halfway between two of the fins. We'll use this line for the rail buttons.

There aren't many pens that will mark on the Quantum tubing. One good choice is a fine tip permanent marker such as a Sharpie.

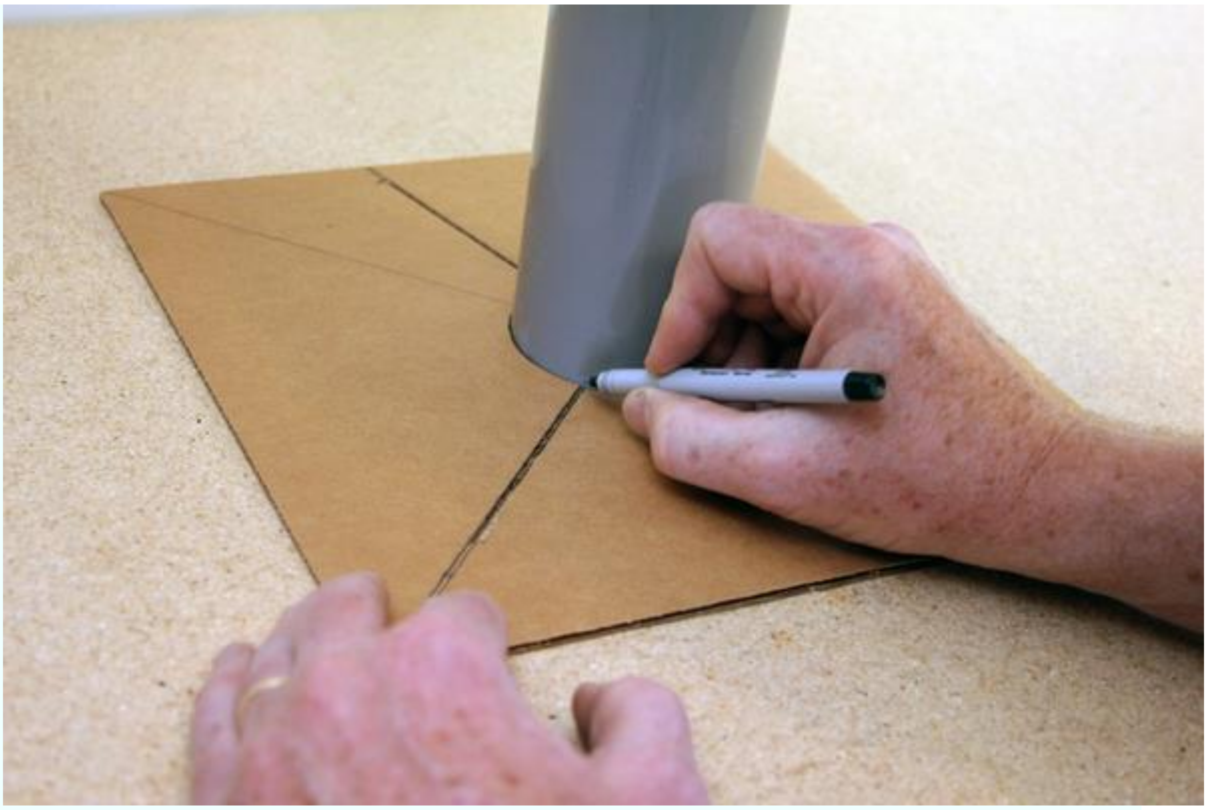


Figure 6-5. Make a fin guide from corrugated cardboard and mark the locations of the fins and rail buttons.

Use a piece of right angle aluminum to draw lines from the base of the tube that are perfectly aligned with the axis of the airframe. You will need two lines 1/16" apart for each fin. These need to run about 5" from the base of the airframe. Draw a line along the entire length of the airframe for the rail buttons.

The fins will be 1/2" from the bottom of the airframe tube. The root of each fin is 4" long. Mark the ends of the fin slots with horizontal marks 1/2" and 4 1/2" from the bottom of the body tube (Figure 6-6).

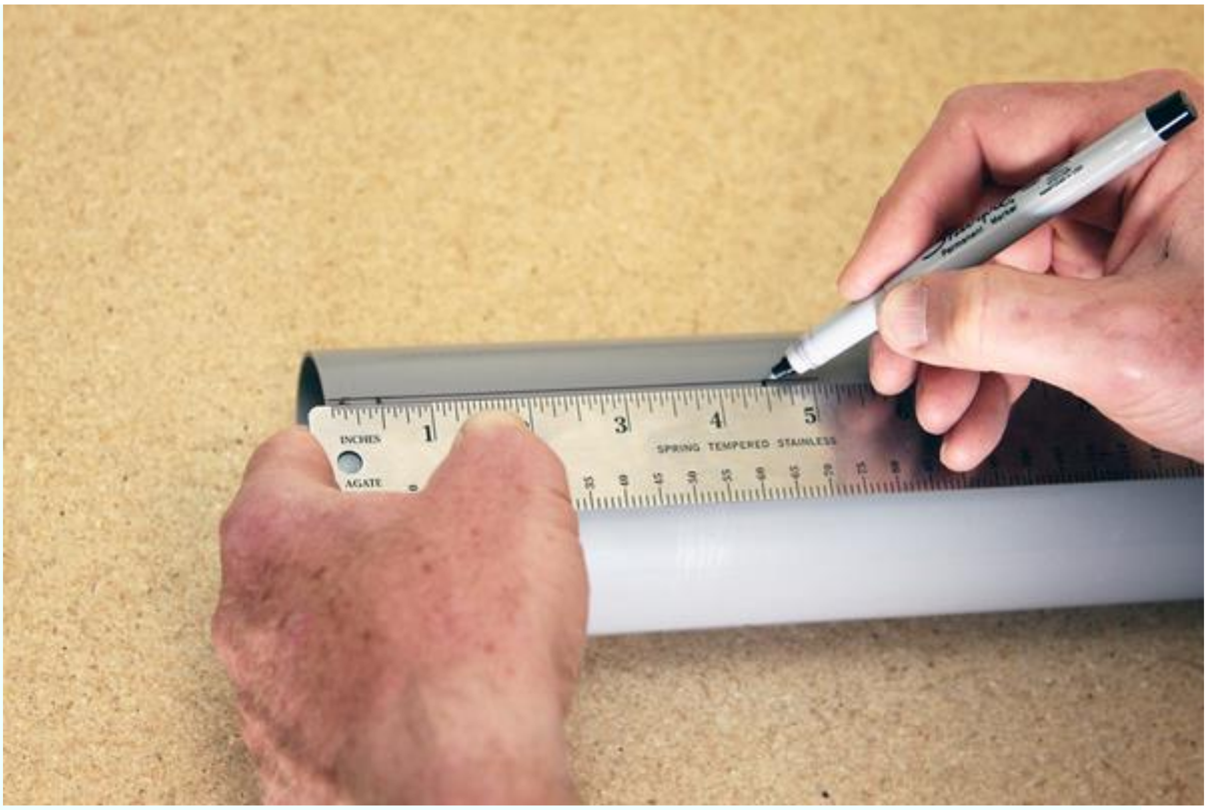


Figure 6-6. Use a fine-tip marker to mark the sides of the fin slots and the locations of the rail buttons.

The aft rail button will be 5 1/2” from the base of the rocket. Mark this location on the rail button line. The forward rail button will be 5” from the forward end of the body tube. Mark that location, too. As you will see later, the locations of the rail buttons are fairly critical. Read the instructions carefully before deciding to move the rail buttons.

There are a number of ways to cut fin slots in plastic body tubes. Pretty much any fine-toothed saw will work, but using a saw generally means cutting both sides of the fin slot, and it’s really hard to get parallel lines that way. A web search will reveal all sorts of jigs and forms to help you cut a perfect fin slot. Personally, I’ve found a Dremel tool, a few plastic cutting disks, and some care works just fine.

Start by stacking enough cutting disks to form a stack 1/16” thick. Using a stack of cutting disks the same thickness as the fin means you only have to make one cut to create the fin slot. With the disks in place, slowly and carefully cut the fin slot, using one of the lines as a guide. Plastic frequently forms small nibs as it melts during cutting, and these frequently reattach themselves as you cut. You can see some in Figure 6-7. Don’t worry about these while you are cutting the slot.

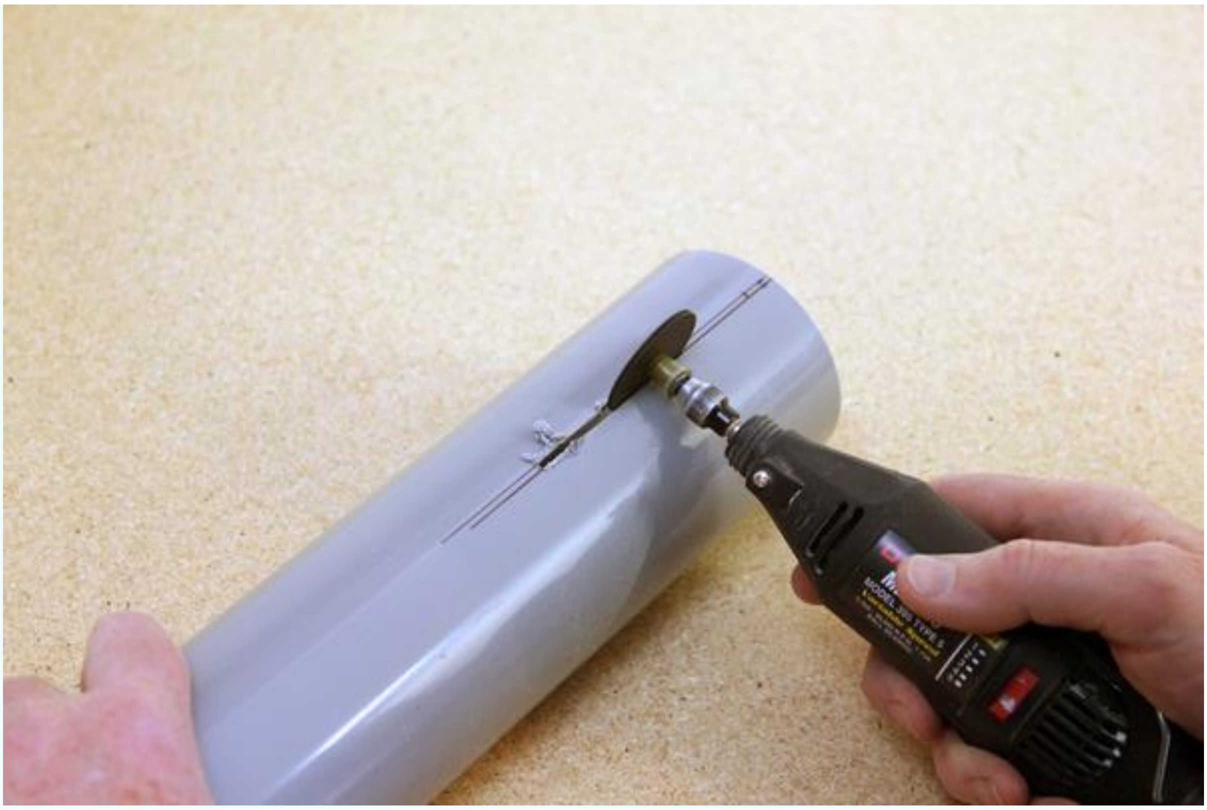


Figure 6-7. Stack enough cutting disks to form a cutting disk 1/16” thick, then carefully cut the fin slots.

Once the fin slot is cut, test fit one of the fins, trimming any areas that need it. Use a hobby knife or medium grit sandpaper to clean off any nibs of extra plastic.

Drill a 3/16” hole at the forward and rear rail button locations.

Callisto’s shock cord passed through the forward centering ring and was glued around the motor mount. That method will work for Deimos, too, but we’re going to try another method. This is a case where there are a lot of right ways to get the job done, and you may end up preferring one or another. Personally, I switch based on the size and materials used for the rocket.

This time we’re going to mount an eye bolt in the forward centering ring and tie off the shock cord to the eye bolt. We’ll cover the lower part of the shock cord with Nomex to protect it from the ejection charge.

If you bought an eye bolt from PML, drill a 3/16” hole through one of the centering rings. If you are using a different eye bolt, check the shaft size and drill an appropriately sized hole. The nut for the eye bolt is small enough that a sharp tug, perhaps from a parachute opening at high speed, could easily pull the nut through the bulkhead. You need to add a washer to spread the force over a larger area. The problem is that a standard circular washer is also a bit small. One solution, seen in Figure 6-8, is to cut a length from a strip of aluminum and drill a hole through the center, using the long strip as a washer.

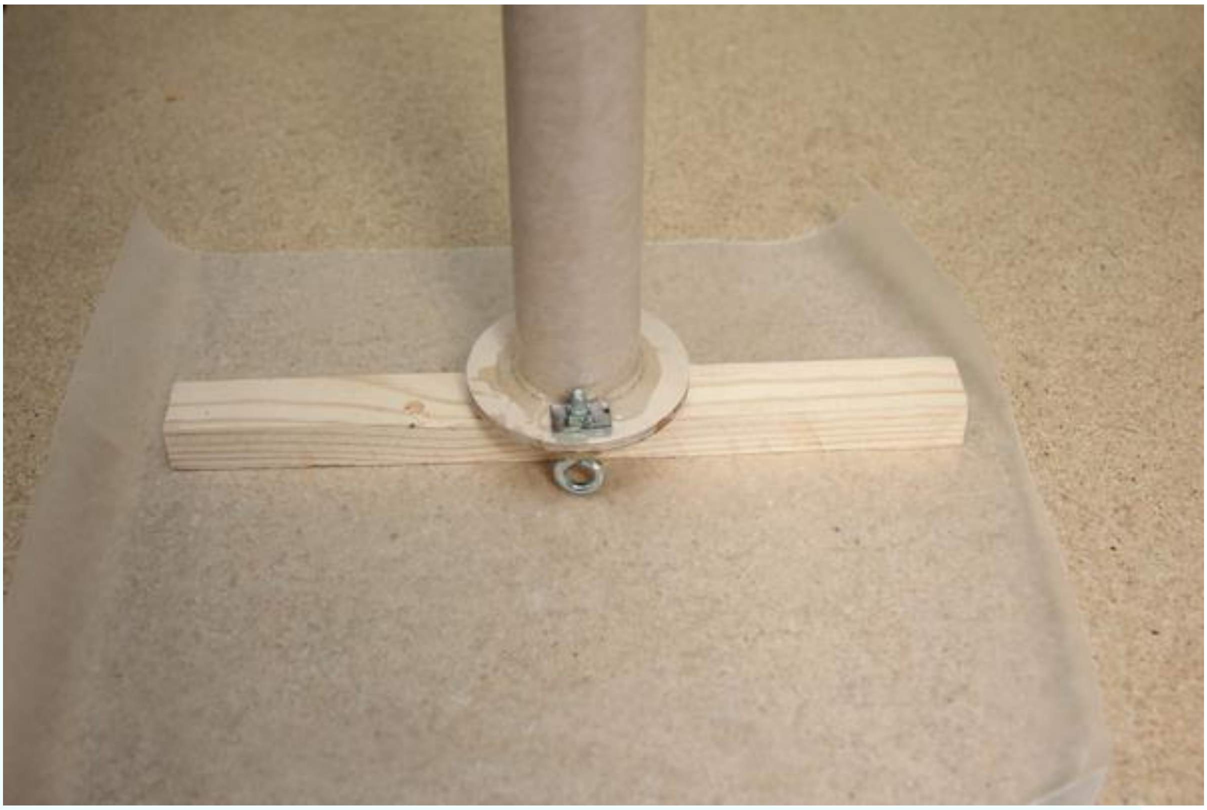


Figure 6-8. Attach an eye bolt to the forward centering ring and glue the centering ring 1/4” from the end of the motor mount.

After dry fitting the parts, screw the pieces together and apply a generous amount of fast-curing epoxy. Form a thick fillet where the motor mount meets the centering ring, and don’t be shy about slopping some of the epoxy across the bolt for the eye bolt. You may find it useful, as I did, to stand the motor mount on a piece of scrap wood so the eye bolt does not push the centering ring out of alignment as the glue sets.

Once the glue sets, turn the motor mount over and apply another fillet on the forward side of the joint between the motor mount and centering ring (see Figure 6-9). Extra epoxy is a good thing; it strengthens the wood.

There are a lot of choices when it comes to buying shock cord. We used nylon webbing for Callisto, and that’s a really good choice for smaller rockets. Nylon webbing like the kind used for Callisto is rated at 1,000 lb. Knots reduce the strength, generally by about 20%. Exposure to hot ejection gases and general wear and tear also reduce the strength. I generally assume the working strength is no more than half of the rated strength. Still, 500 lb is a lot, and would probably work fine for Deimos.

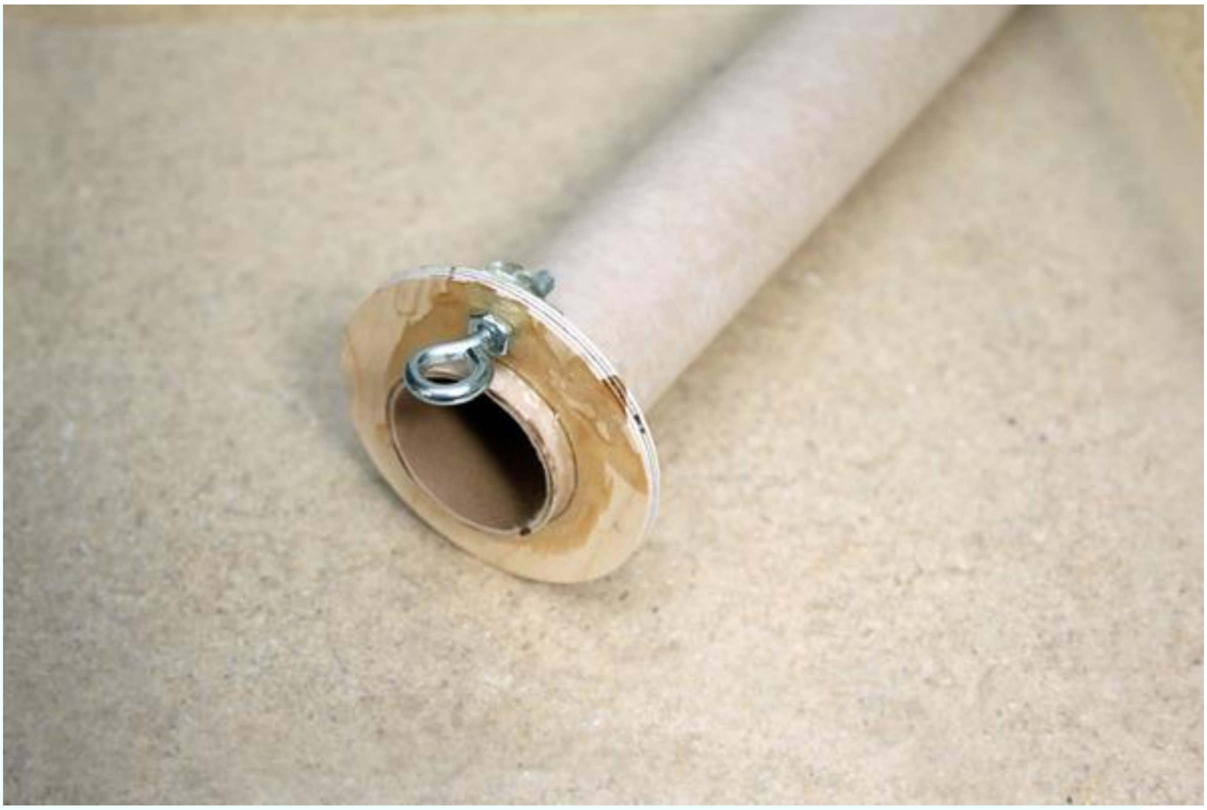


Figure 6-9. Apply another fillet on the forward joint between the motor mount and centering ring.

As rockets get larger, though, most people switch to stronger shock cords. The next strongest commonly used material is called tubular nylon. It comes in a variety of sizes. The 9/16” size is perfectly adequate for all of the remaining rockets in this book. It’s actually both more flexible and stronger than the nylon strap we used for

Callisto, with a rating of 2,000 lb. You can buy the tubular nylon for this rocket from PML when you order all of the other parts, or you can buy a spool of tubular nylon from a company like Country Brooke Design, which specializes in straps of all kinds.

Like nylon strapping, tubular nylon needs some protection from the heat of an ejection charge. You could use a shock cord protector like the one we used for Callisto. An alternative to a commercial shock cord protector is 1/4” woven Nomex. It’s both cheaper and more effective in the long run.

Shock cords should be 3–5 times the length of the rocket, and Deimos is about 5 feet long. Cut a 20-foot length of 7/16” tubular nylon for the shock cord.

Cut a 2-foot-long piece of 1/4”-diameter Nomex tube to cover the portion of the shock cord that will be closest to the ejection charge. Playing around with the stuff, you’ll quickly find that it is a lot like the finger cuffs you might have played with as a child. It’s easy to push something into the tube of Nomex, but pulling the Nomex over the end of the tubular nylon is almost impossible. The solution is to find a short piece of something smooth and round that is about the same diameter as the bunched-up tubular nylon. I used a scrap of aluminum tubing. First, push the Nomex sheath over the aluminum rod. It bunches up as you push, expanding the tubing so it slips over the aluminum tube rather easily. Now tape the tubular nylon to the end of the aluminum tube and push the Nomex onto the tubular nylon. It really pushes on rather easily. See Figure 6-10.

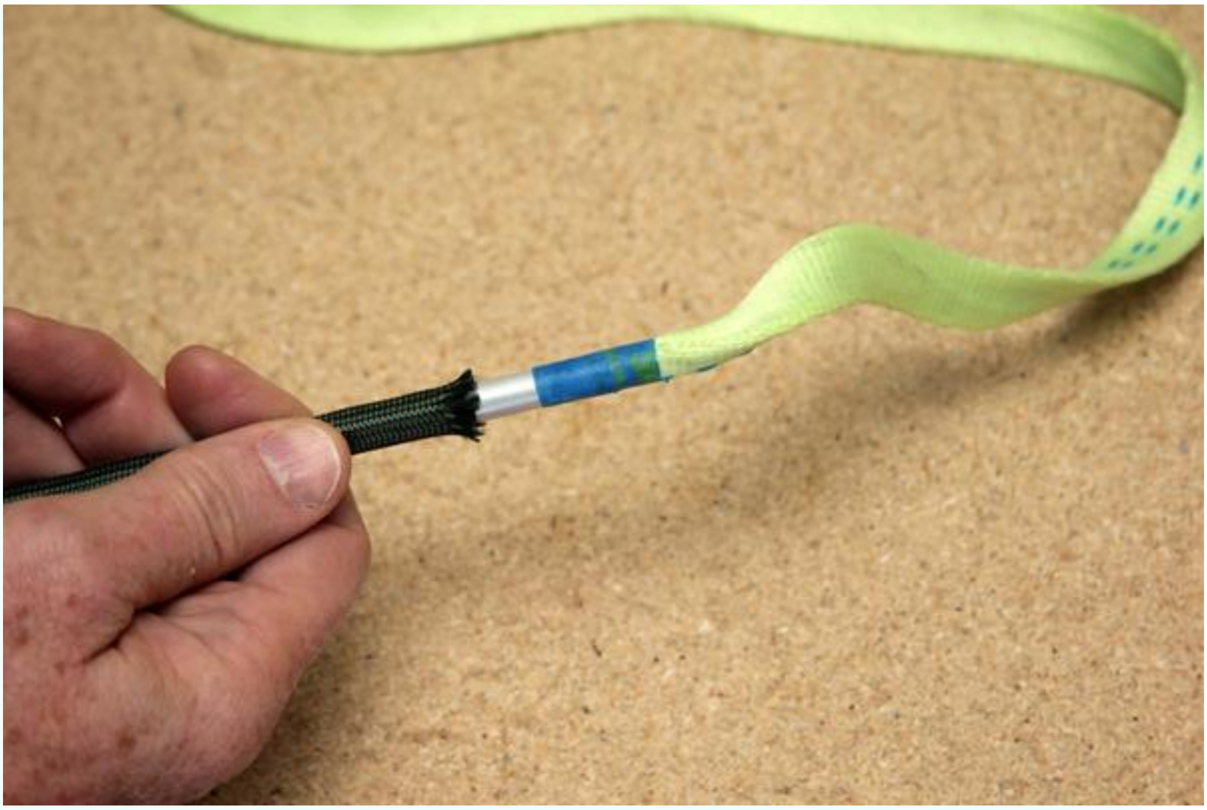


Figure 6-10. Cut a 20-foot length of tubular nylon and a 2-foot length of Nomex. Using an aluminum tube or dowel, push the Nomex tubing onto the tube. Tape the tube to the tubular nylon, and then slide the Nomex onto the tubular nylon.

Use a buntline knot to attach the tubular nylon to the eye bolt (see Figure 6-11). Apply some epoxy around the end of the knot and the edge of the Nomex sleeve. This doesn’t really help the knot strength, but it does add some protection from the ejection charge, and helps keep the Nomex webbing from unraveling.

Dry fit the lower centering ring, fins, and motor retainer so you understand how they will all fit together (see Figure 6-12).

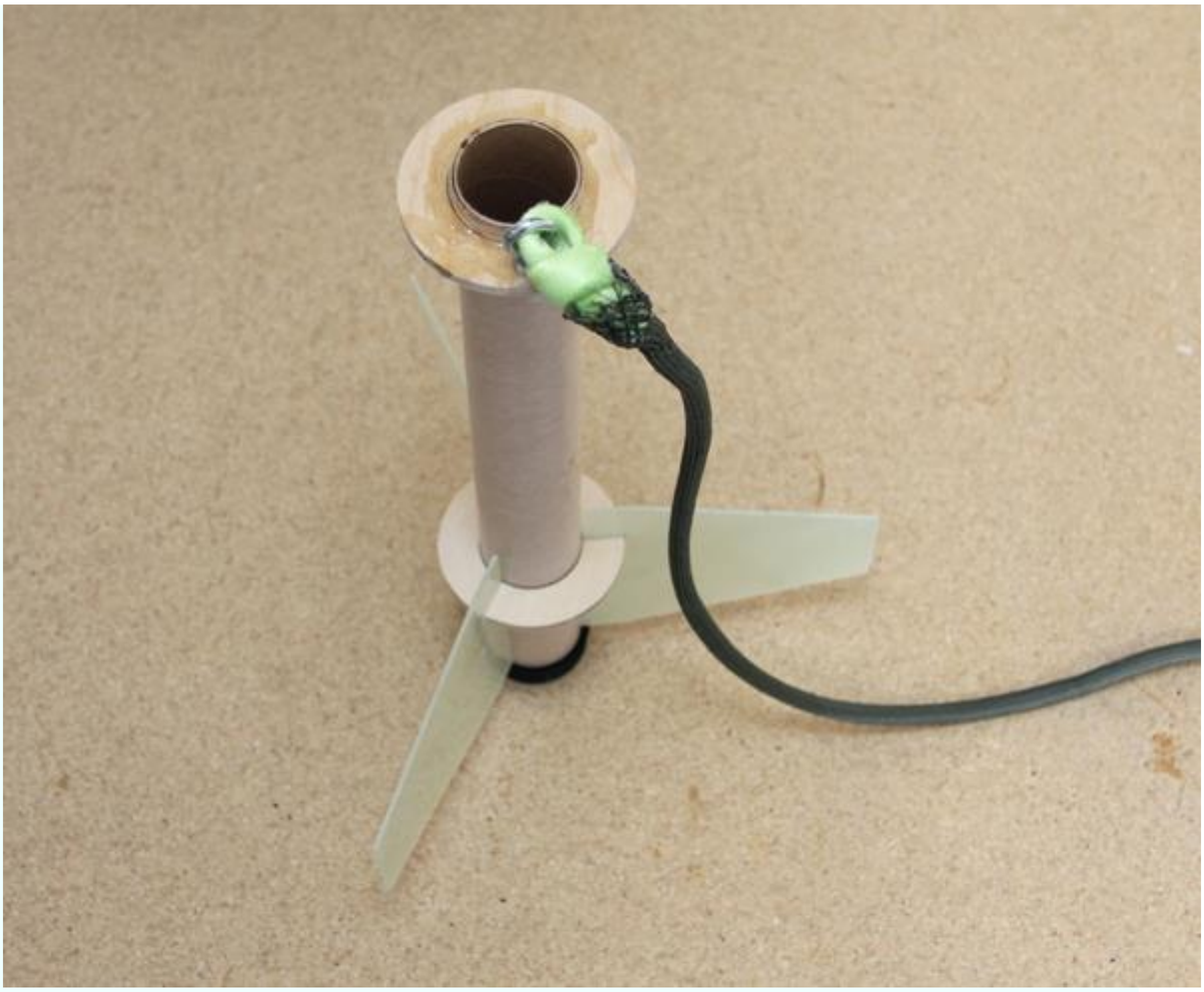


Figure 6-11. Fasten the tubular nylon to the eye bolt using a buntline knot. Apply a thin layer of epoxy to the exposed nylon to help protect it from the ejection charge. A little will get on the Nomex, which will help keep it from unraveling.

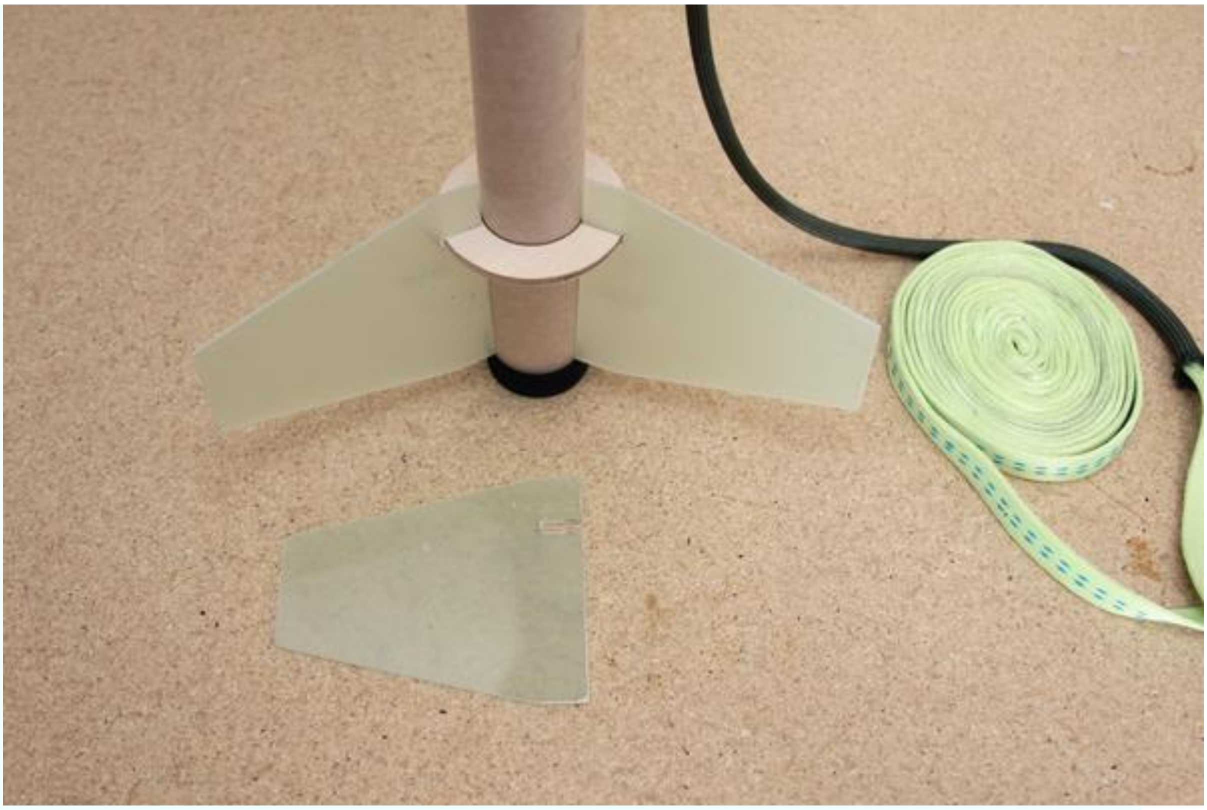


Figure 6-12. Here's how the fins and centering ring will be positioned in the finished rocket.

Glue doesn't hold well to the smooth Quantum tubing. Always scuff up the Quantum tubing before gluing. If your hands are small enough, or if you have a willing child nearby, you can do this with a sheet of sandpaper. My hands are not that small, and the grandchildren were not around, so I taped a piece of sandpaper around a dowel (see Figure 6-13). Scuff up the area around the fin slots, both inside and outside the rocket. Scuff rings 11 3/4" and 5 1/2" into the rocket; this is where the centering rings will rest. Finally, scuff up the area on the inside of the rocket behind each of the rail button holes.

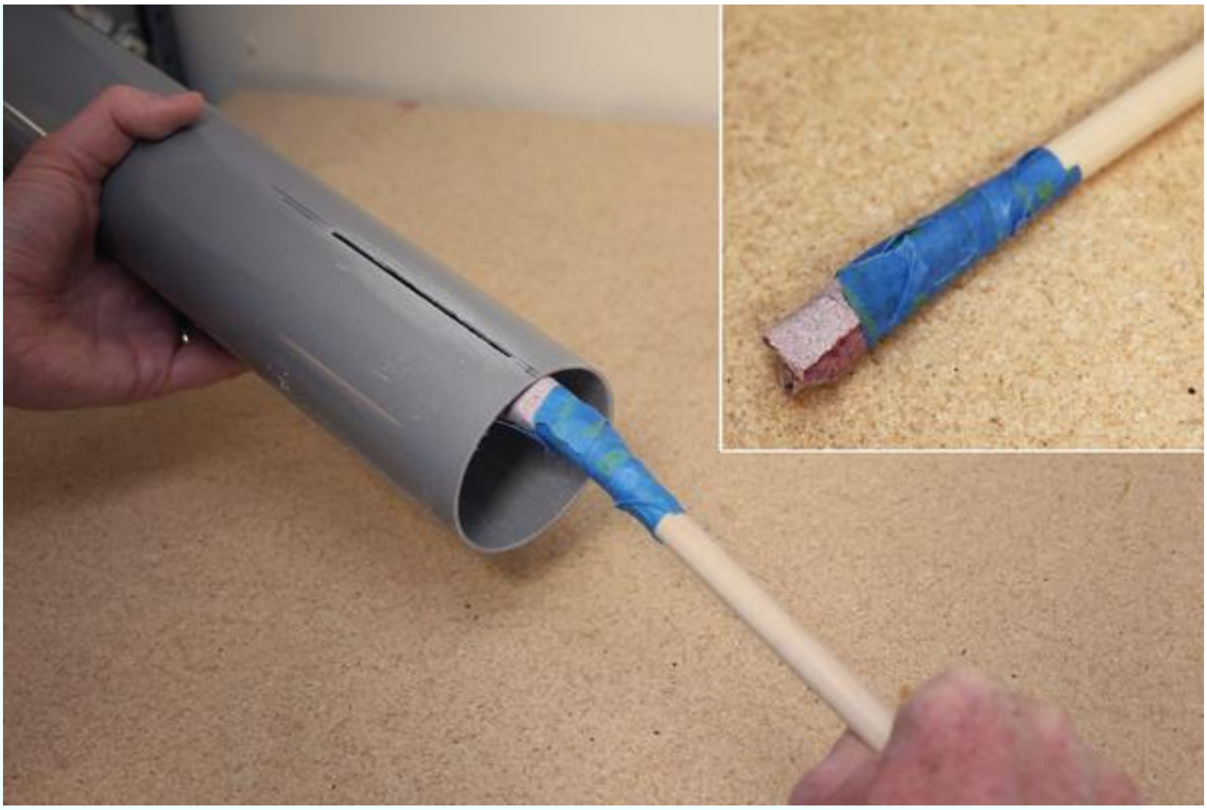


Figure 6-13. Scuff all areas of the tube where glue will be applied. Don’t forget the inside of the rocket, especially the area where the centering rings will be glued.

The next step is to glue the motor mount in place. You will apply a generous amount of slow-cure epoxy in a ring, then push the motor mount and centering ring through the epoxy to form a fillet and smear glue between the airframe tube and centering ring.

You can slide the motor mount into the rocket from either the front or the back. Each has advantages and disadvantages. Sliding it in from the front means you will have to push it with something, probably a dowel, and you risk getting glue on the aft end of the motor mount tube. Sliding it in from the bottom makes it likely you will get glue on the shock cord, which is already attached to the forward centering ring. I chose to slide the motor mount in from the front. If you decide to slide it in from the rear, pack the centering ring in a plastic trash bag. You will probably get glue on the trash bag, but you can toss it once the glue sets.

Start by dry fitting all of the parts. Make sure the aft centering ring is loose enough to pull out with dental floss, as we did for Callisto. Tie a couple of loops of dental floss around the aft centering ring to use as a handle to remove the centering ring once the glue sets on the forward centering ring.

Use a dowel or a piece of scrap wood to apply a very generous amount of fast-cure epoxy just above the location where the forward centering ring will rest (see Figure 6-14).

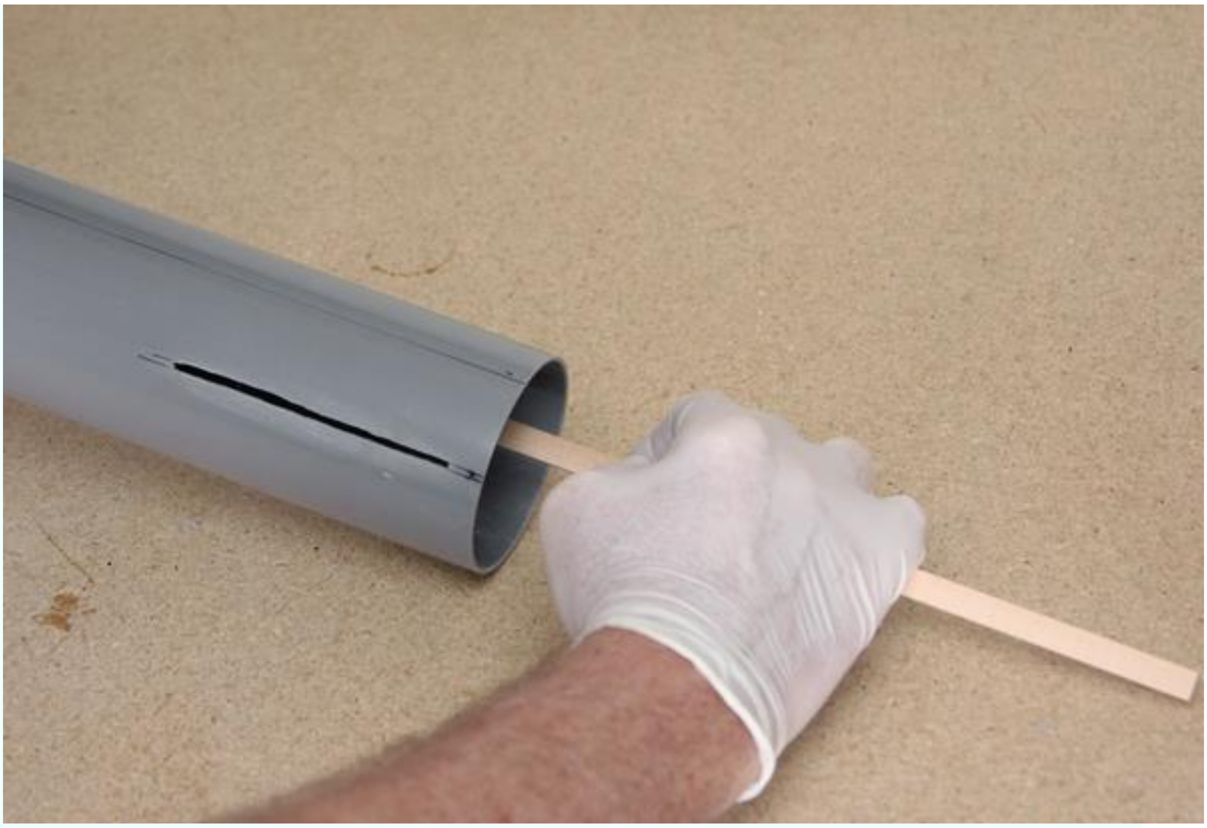


Figure 6-14. Apply glue so the forward centering ring will slide through the glue as you push it into place, forming a nice fillet.

Slide the motor mount into place. Make sure there is no excess glue on the base of the motor mount, removing it with rubbing alcohol if there is any stray glue. Slide the aft centering ring into place to keep the motor mount perfectly centered, but do not glue the aft centering ring into place (see Figure 6-15).

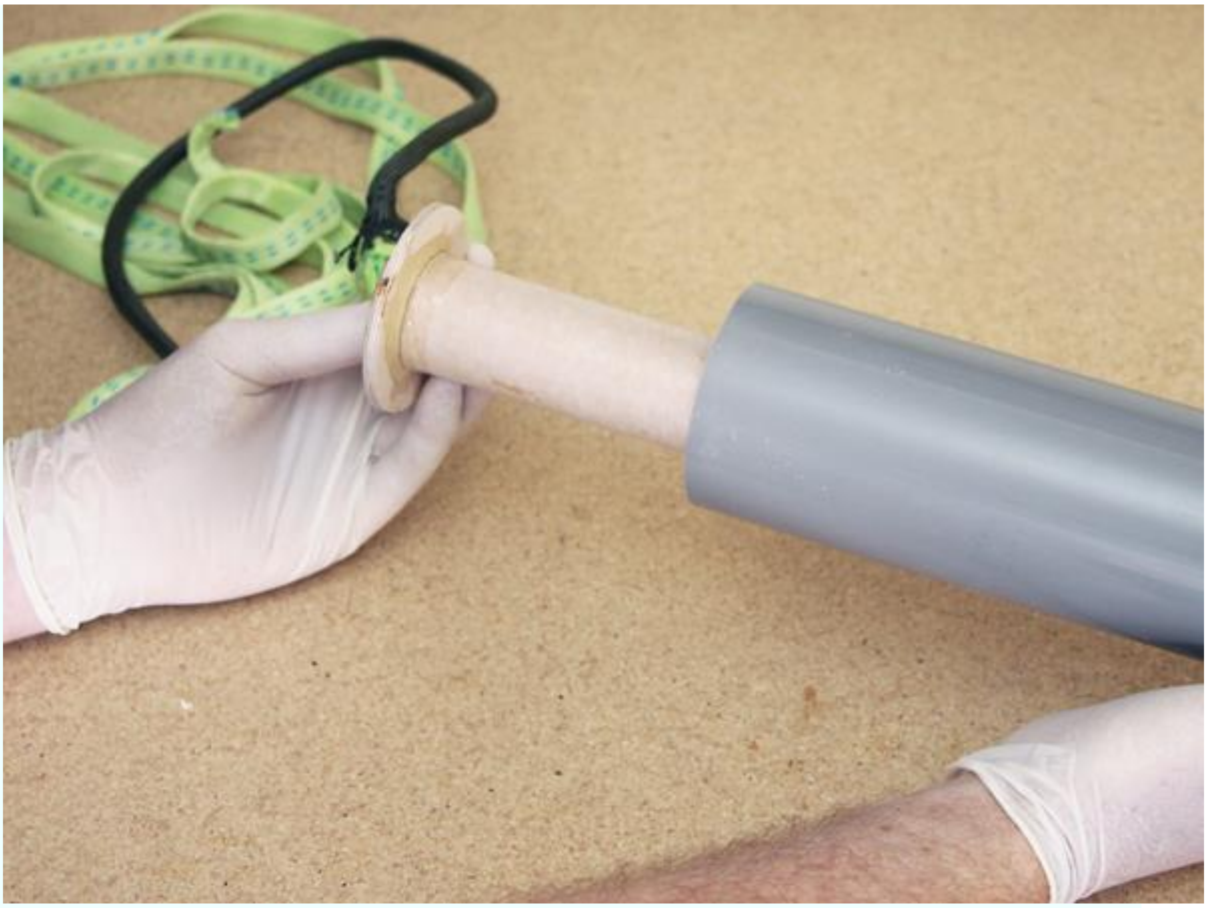


Figure 6-15. Slide the motor mount through the glue, then push the aft centering ring just inside the bottom of the rocket to keep the motor tube centered while the glue sets.

The aft rail button will be in front of the aft centering ring, so it needs to be installed before you put the centering ring in place. Rough up one side of a large, flat nut and glue it inside the airframe. Use a piece of tape wrapped inside out around the end of a dowel or a piece of scrap wood to hold the nut in position. Screw the rail button in place to hold the nut while the glue dries, but remove the rail button before the glue dries completely. See “Launch lugs and rail buttons” for some thoughts on where to buy appropriate nuts, or how to make your own from aluminum.

Once the glue dries, screw the rail button in place (see Figure 6-16). If you get sloppy with the glue while installing the aft centering ring, it could fill up the hole in the nut. While it’s nice to be able to replace a worn rail button, the chances you will actually have to do that are smaller than the chance you will glue the hole closed, so it’s worth risking gluing the rail button in place.

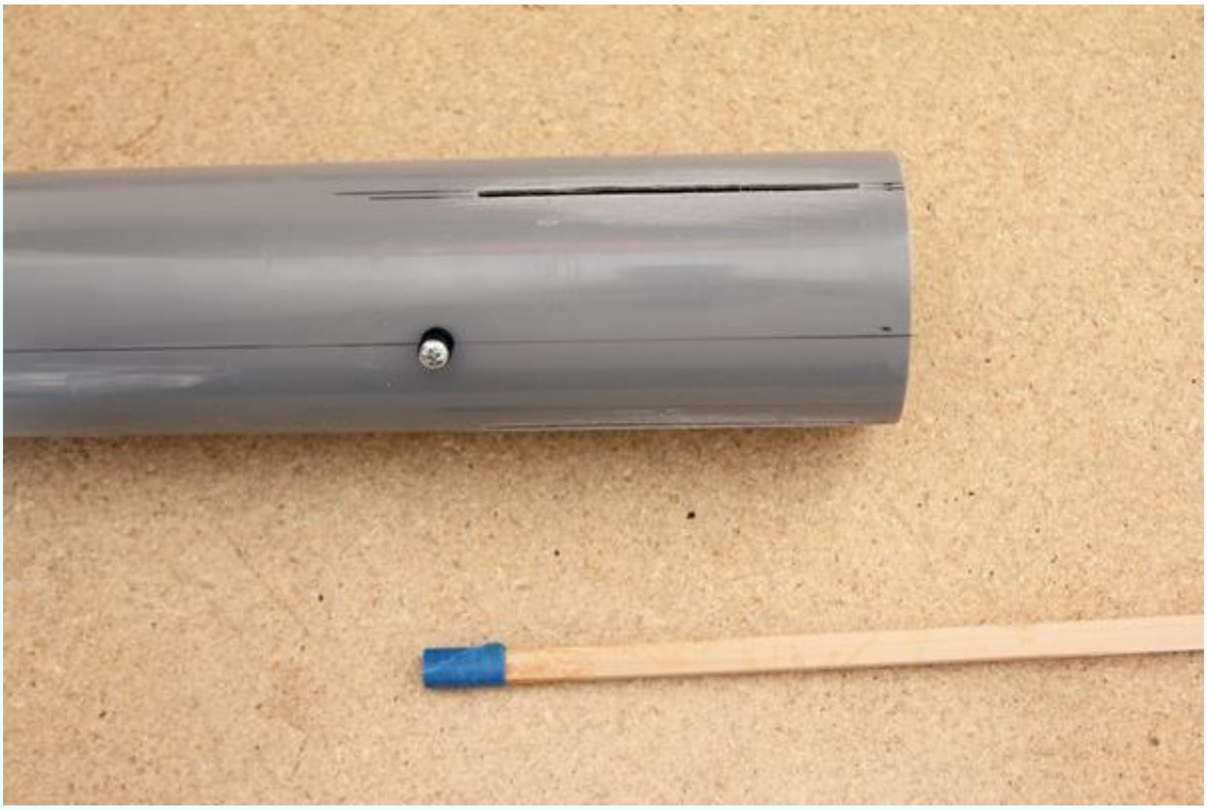


Figure 6-16. Glue the rail button nut in place on the inside of the airframe and install the rail button.

You can install the other rail button at this time, too. Since it is exposed, I generally do not glue the nut in place. Be sure to cut off any excess length on the rail button bolt, though. A rail button bolt that sticks above the nut can easily snag a parachute.

The fiberglass fins need to be scuffed before gluing, just like the Quantum airframe tube. Scuff the entire surface of the tang, extending out onto the main fin surface about 1/8”. While you are at it, round the leading edge, trailing edge, and tip of each fin to reduce drag. Finally, use fine sandpaper to remove the shine on the main part of the fin itself. You don’t need to scuff it as deeply as the areas that need to hold glue, but you do need to roughen the surface a bit so it will hold paint, and that’s easier to do now than with the fins glued in place.

Use a dowel or piece of scrap wood to apply a very generous ring of slow-cure epoxy about 3” inside the airframe and on the motor mount tube. Slide the aft centering ring into place. You can use a thin piece of wood or the edge of a fin to slide it back and forth to the correct spot.

Apply epoxy to the root edge of each fin and push them into place. Slide the fin template into place to keep the fins positioned while the glue sets (see Figure 6-17). Use a flashlight to carefully check each fin, making sure the root edge of the fin is pressed firmly against the motor mount. Stand the rocket upright as it dries so the glue flows down, forming a nice fillet on the top of the centering ring. Use a flashlight to check the fins several times as the glue sets, making sure they don't pull away from the motor mount.

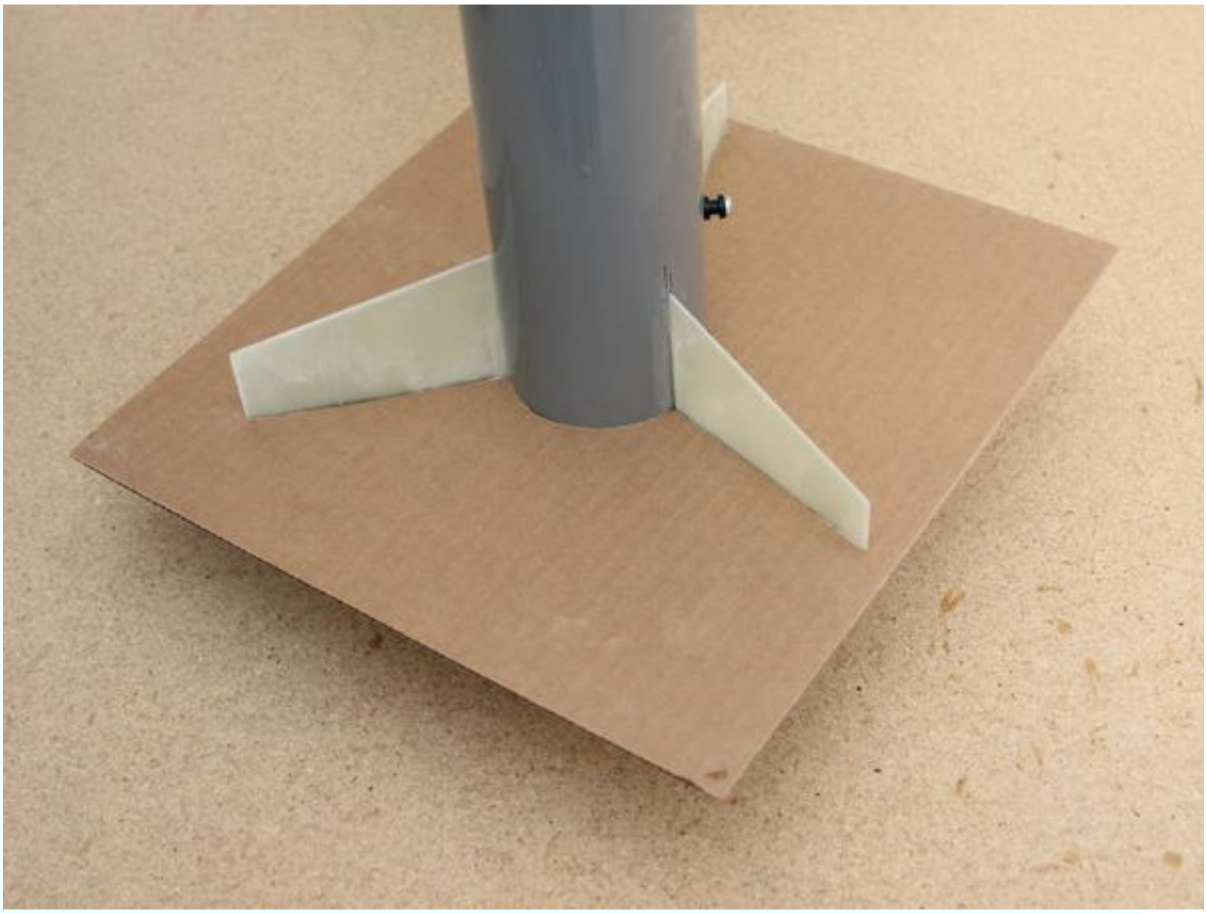


Figure 6-17. Glue the fins and forward centering ring in place.

Apply very generous fillets to all 18 joints between a tube and a fin (see Figure 6-18). Refer to "Installing the Fins" for details on how to properly do this. Dribble some epoxy onto the centering ring to form thick fillets on the underside of the centering ring.

You really can't use too much glue on this step, although you can get it in the wrong place. Keep the area of the motor mount from the bottom of the fins to the end free of glue so the motor retainer will fit in place. This rocket is designed to accommodate a forked tube coupler, so be sure there is no glue on the inside of the airframe tube other than the fillets, which should not extend more than 1/4” to either side of the fin. Use rubbing alcohol to clean up any stray glue.

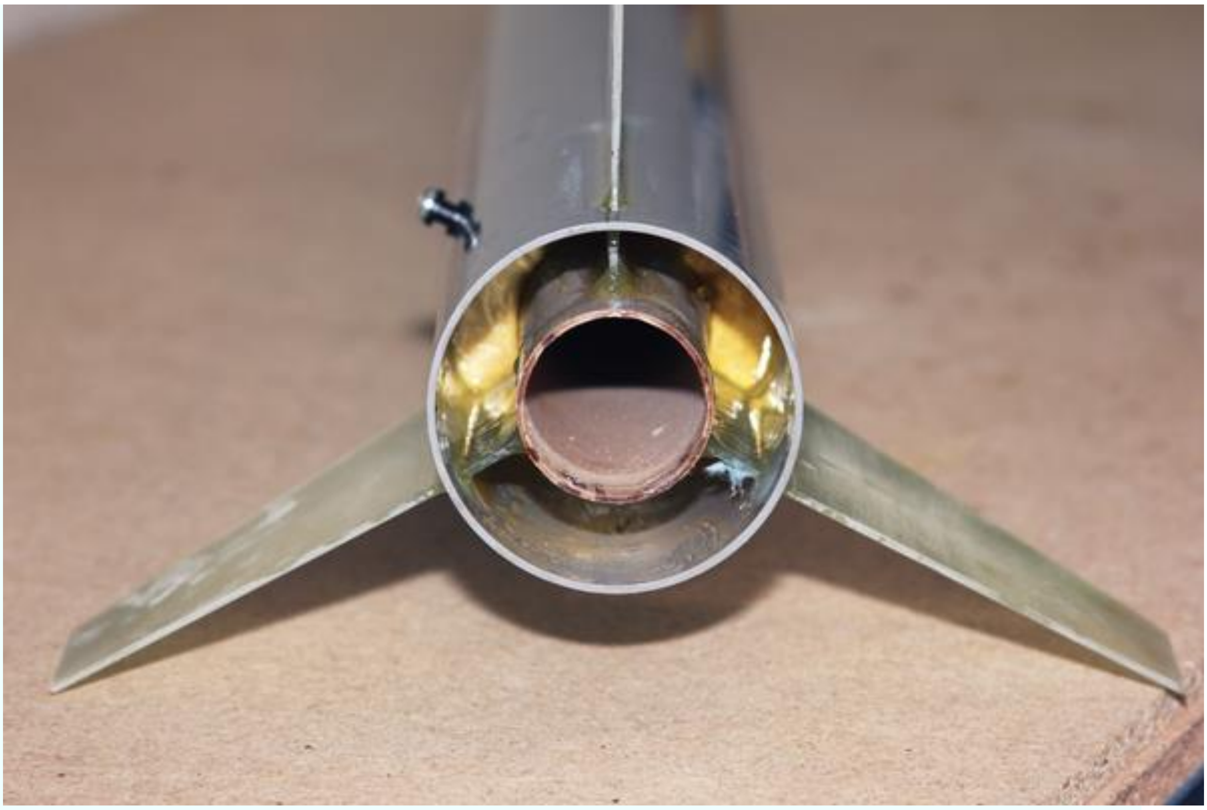


Figure 6-18. Apply generous fillets to the underside of the centering ring and all locations where the fin touches a body tube.

Use JB Weld or another heat-resistant epoxy to glue the motor retainer in place (see Figure 6-19).

The last step on the booster is to attach two quick links. The shock cord is rated at 2,000 lb. Accounting for wear and tear as well as knots, we can safely rely on about 1,000 lb of strength. Pick quick links rated about the same. I used 3/16” Blue Hawk quick links from Lowe’s, rated at 800 lb, but there are many similar products around.

Tie an overhand knot 1/3 of the distance from the free end of the shock cord and place one of the quick links at this location. This is where the parachute will attach. Tie the loose end to the second quick link using a buntline knot (see Figure 6-20). To prevent the knot from accidentally unraveling, tack the end in place using a small bit of epoxy.

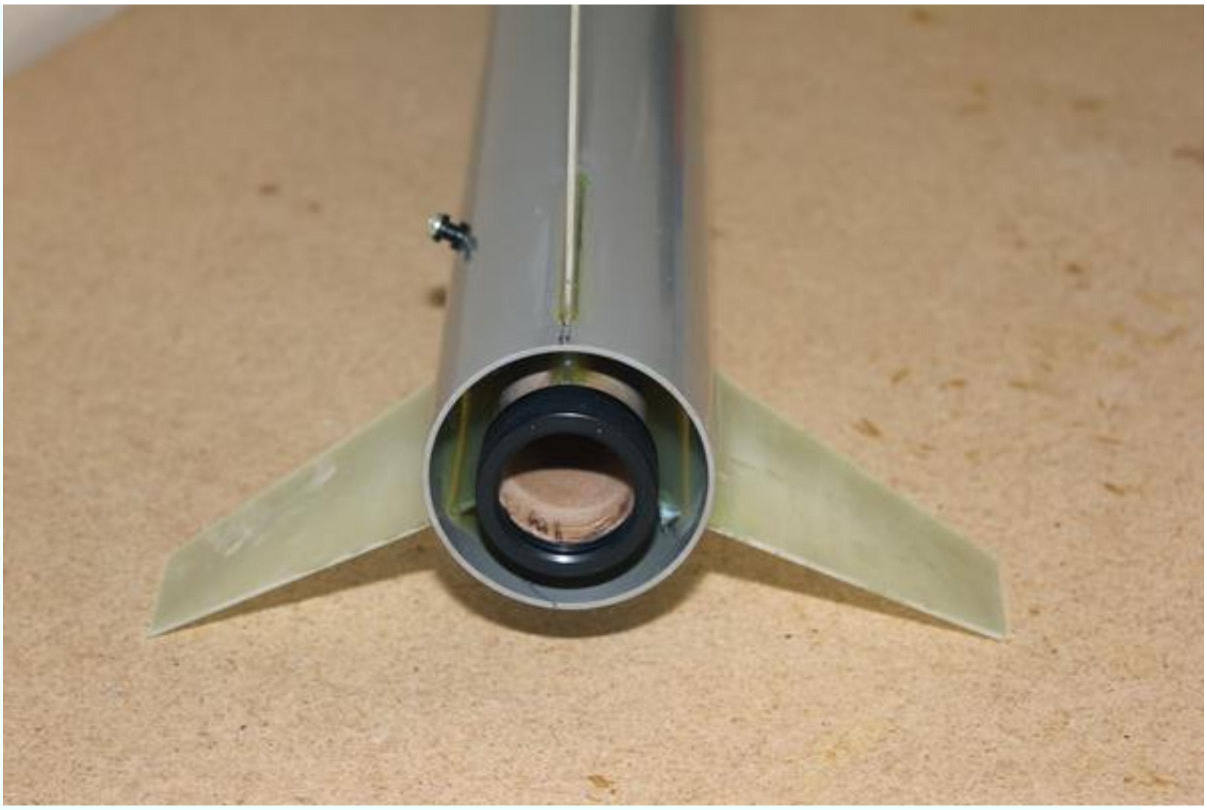


Figure 6-19. Glue the motor retainer in place with JB Weld.

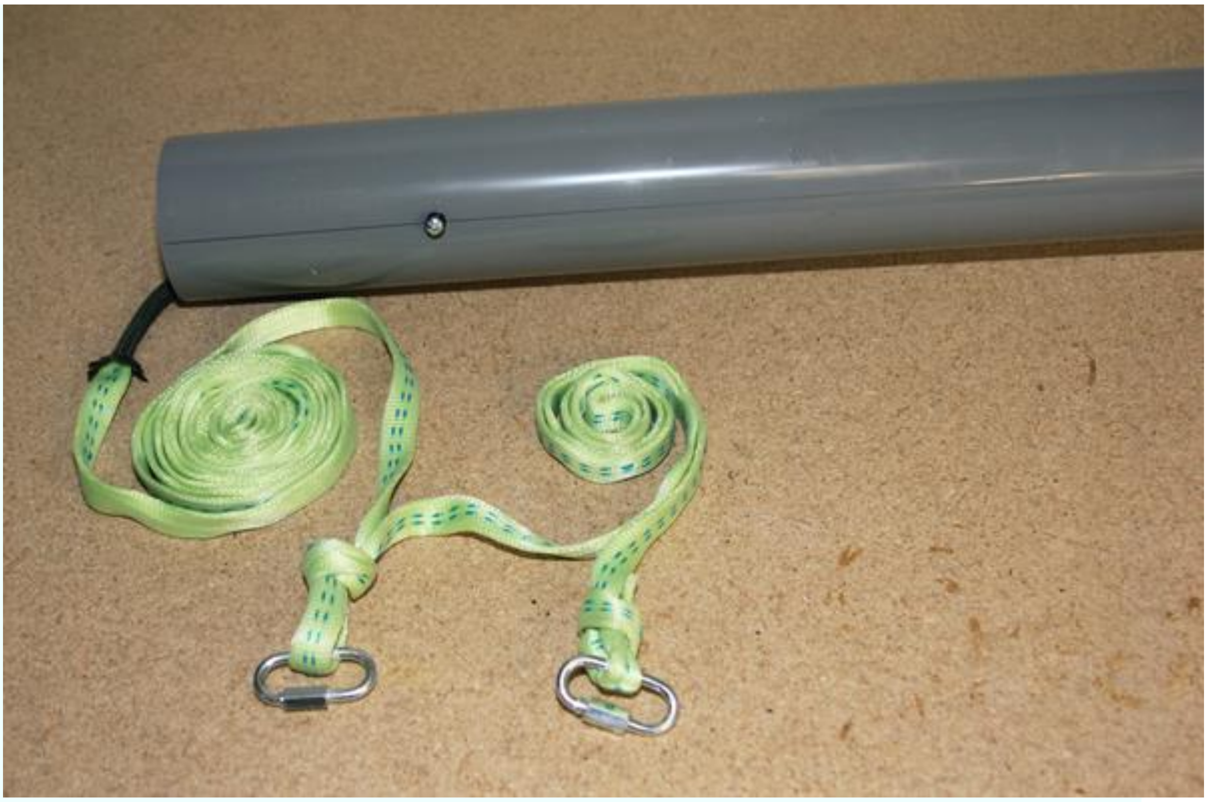


Figure 6-20. Fasten two quick links on the shock cord, one at the end and the other 1/3 of the way from the end.

PML sells a kit for making a payload bay. It comes with a 12”-long piece of Quantum tubing, a tube coupler, a bulk plate, and an eye bolt with a washer. It’s a pretty good deal, but you may end up needing more airframe tubing for one of the dual-deploy mechanisms described later in the book. You can either buy the payload bay kit and get another tube later, or just buy a 36”-long tube and get the other parts separately.

If you buy the longer tube, cut off a 12” piece.

As shown in Figure 6-21, fasten an eye bolt in a 3/16” bulk plate, using a large washer to spread the load from a sharp tug. Glue the bulk plate 1/4” from one end of a 5”-long tube coupler. Apply generous fillets on both sides of the bulk plate. Coat the bottom of the bulk plate with a thin layer of epoxy to protect it from ejection charges.

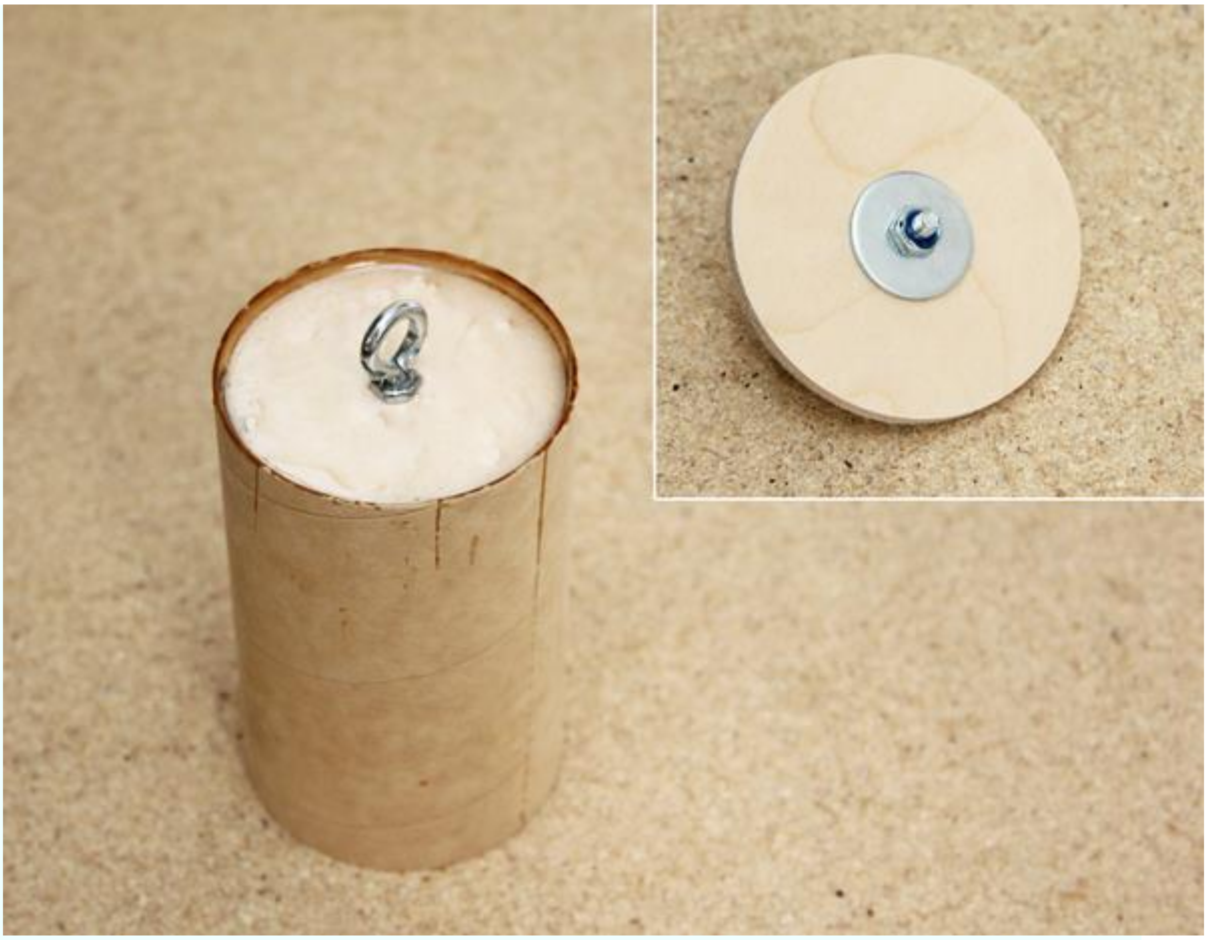


Figure 6-21. Mount an eye bolt in the bulk plate and glue the bulk plate into the tube coupler.

Rough up the lower 2” of the inside of the payload bay airframe tube with medium grit sandpaper. Apply a thin layer of epoxy to the bottom 1 1/2” or so of the tube, then slide the tube coupler into place.

Drill three evenly spaced pilot holes through both the body tube and nose cone, then attach the nose cone with 1/2”-long #4 pan head screws (see Figure 6-22).

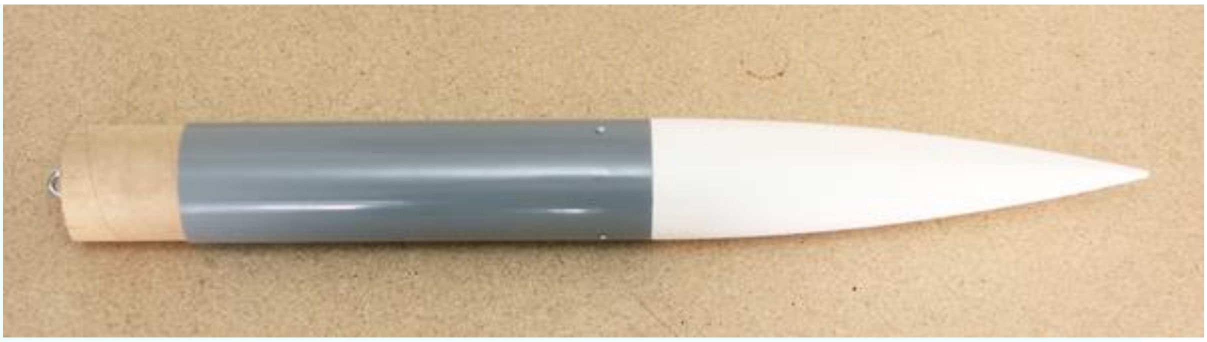


Figure 6-22. Glue the tube coupler into the airframe and add screws to hold the nose cone in place.

That completes the basic construction for Deimos (see Figure 6-23). There is a little preparation left to do before painting, though.

Permanent markers may bleed through paint. Save yourself some grief by removing any remaining marker lines. Rubbing alcohol and a paper towel work well.

While both Quantum tubing and fiberglass are very easy to paint, neither holds paint well until it has been prepared. Use fine sandpaper to sand the Quantum airframe tube and the fiberglass until they have a satin finish, not a glossy one. You don’t want deep scratches from medium grit sandpaper like the ones we used to scuff surfaces before gluing. Just sand the surfaces until they are not shiny.

Of course, the nose cone will have flash from the molding process, and that needs to be removed before painting, too.

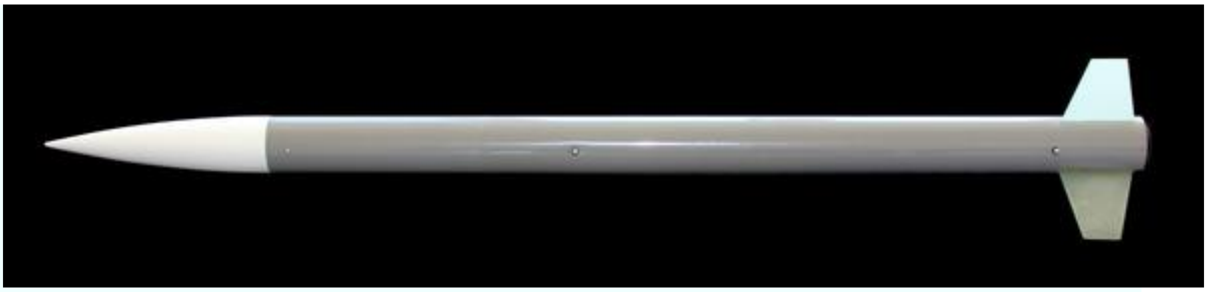


Figure 6-23. Deimos is ready for finishing!

Phobos: A Fiberglass Level 2 Rocket

Phobos

Phobos (Figure 6-24) is a near twin for Deimos, the first rocket in this chapter, and the moon it is named after is also very similar to Deimos. These twin rockets are designed so you can combine them into a single two-stage rocket.

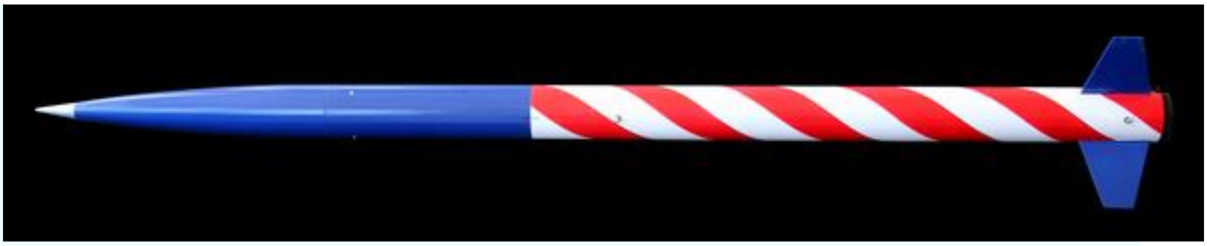


Figure 6-24. Phobos is a sturdy fiberglass Level 2 rocket, built for supersonic flight.

Be sure to build and fly Callisto or Deimos before building Phobos. For reasons of both safety and cost, it’s better to get started with a paper or plastic rocket before moving on to fiberglass.

While Phobos is designed and built with fiberglass parts, the construction is essentially the same if you use carbon fiber. Carbon fiber is lighter than fiberglass, but keep in mind that carbon fiber is opaque to radio waves. If you switch to carbon fiber, be sure to use fiberglass for the payload or nose cone so you have somewhere to put the antenna for your tracking device.

We’ve used components from two different companies for our first two rockets. This time we’ll switch to a third great company, Wildman.

Wildman is both a manufacturer and a reseller. You can, for example, buy the LOC Precision parts for Callisto from Wildman. The fiberglass parts we will use are unique to Wildman, though.

There are other alternatives. Madcow Rocketry also supplies fiberglass rocket parts. We’ll use their parts for Ganymede, the Level 3 rocket in Chapter 13, and you could substitute their parts for the fiberglass components shown here. PML also manufactures phenolic body tubes that are wrapped in fiberglass. As you know, phenolic tubes are made of very thick paper and resin, but the fiberglass wrap provides plenty of strength for this rocket. You could rework the rocket to use these body tubes, too.

With the exception of the fins, the part numbers shown in Table 6-3 are from Wildman. Like Deimos, I bought the fins for Phobos from PML so I didn’t have to cut them myself. Like many other companies, Wildman sells sheets of 0.062”-thick G10 fiberglass for fins and bulkheads, so you can order fin material from Wildman and cut your own. The parts listed here are shown for reference in Figure 6-25.

Part	**Description**
Nose cone	The nose cone for the rocket.
Booster airframe, 75 mm diameter, 36” long	Fiberglass tubing, sold by the foot.
Payload airframe, 75 mm diameter, 12” long	A second piece of fiberglass tubing for the payload bay.
Tube coupler, 6” long	Fiberglass tube coupler for 75 mm airframe tubes.
Bulk plate	This bulk plate forms the base of the payload bay.

Part	Description
Eye bolt	The eye bolt is attached to the bulk plate. It is used to attach the shock cord that holds the booster to the payload bay. The Wildman eye bolt has a 1/4-20 thread.
Washer	The washer is used to spread the force across the fiberglass bulk plate. Use at least a 3/16” washer.
Fins (3)	PML sells precut fiberglass fins in a variety of shapes and sizes, and offers a cutting service for custom fins. You can also order G10 fiberglass sheets from Wildman and cut your own fins.
54 mm motor tube, 24”	You can substitute phenolic tubes to reduce weight and cost, or use this fiberglass tube for an all-glass rocket that is built to last.
Centering rings (2)	These fiberglass centering rings form a solid motor mount when used with a 54 mm fiberglass motor tube, but you can certainly substitute plywood centering rings to cut the cost and weight a bit.
Motor retainer	Wildman caries several sizes of motor retainers for various tubes. Be sure to get the one listed if you are using a Wildman fiberglass motor tube. If you switch to a phenolic tube, be sure to switch the motor retainer you order, too.
Rail buttons (2)	Wildman offers the same type of rail buttons you used on Callisto and Deimos.
Nuts for rail buttons (2)	You can buy these or make them from 1/8” x 3/4” aluminum stock, as we did for Callisto and Deimos.
Quick links (2)	Get quick links rated for at least 800 pounds for this rocket. Wildman doesn’t carry them as I write this, but quick links are available elsewhere. Check Amazon or your local hardware store.
Tubular nylon	Sold by the foot from Wildman. You need 20 feet for this

Part	Description
	rocket, but you will need more for dual deployment, so plan ahead.
Nomex tubing	You can use a variety of shock cord protectors. The text shows the same Nomex sheath used for Deimos.
Parachute	As designed, this rocket is best flown with a parachute in the 50”–60” range, depending on the size of motor used. See Chapter 9 for ways to find the proper size.
#4 1/2”-long pan head screws (3)	These will be used to secure the nose cone. You can find them at the local hardware store, or order a box online.

Table 6-3. Parts list for Phobos

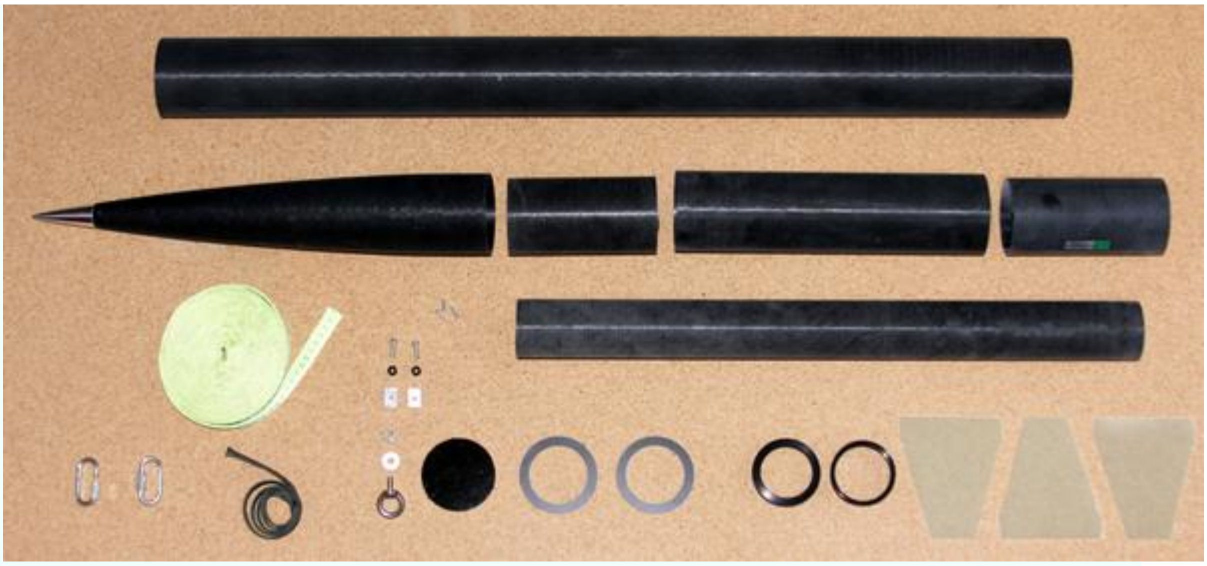


Figure 6-25. Visual parts list. The parachute is not shown.

Some Thoughts on Fiberglass Rockets

Phobos is essentially Deimos built with fiberglass. It uses a 54 mm motor mount rather than the 38 mm motor mount used by Deimos, the aft centering ring on the motor mount is behind the fins, and the shock cord is mounted differently, but that’s really it.

Fiberglass is a much stronger material than Quantum tubing. It also stands up to heat better. Those are both important qualities with a 3” rocket that has a 54 mm motor mount. This rocket can take a small L motor. It can exceed 11,000 feet, over 2 miles high, and hit Mach 1.5. Those speeds are far in excess of the recommended velocity for a Quantum body tube, like the one used for Deimos. While it’s possible to break the sound barrier on other types of body tubes, most fliers recommend fiberglass or carbon fiber body tubes for transonic and supersonic flight.

There are always trade-offs, of course. Fiberglass body tubes are much heavier than paper or Quantum body tubes. While Deimos flies just fine on an H motor, and can even fly on a G motor, the extra weight means that Phobos really needs at least an I motor. Fiberglass is also more expensive than paper or plastic body tubes.

Carbon fiber body tubes reduce the weight a lot, but they come with disadvantages, too. Carbon fiber body tubes are even more expensive than fiberglass. They are also opaque to radio waves, so you either need to use fiberglass for the part of the rocket that holds the radio antenna for your tracker or get really creative with your antenna mount. Other than cost, weight, and opacity to radio waves, carbon fiber is essentially the same as fiberglass for building rockets, so from this point forward, anything we said about fiberglass applies to carbon fiber, too. Carbon fiber is stronger than fiberglass, so we are able to use thinner, lighter carbon fiber tubes than a comparable strength fiberglass tube. This is how we reduce weight using carbon fiber.

Fiberglass is harder to work with because, well, it is harder. You need to allow a bit more time for cutting and sanding with fiberglass. There is also a dust issue to deal with, which we’ll talk about at length in a moment.

And then there is the safety issue. The heavy paper and plastic body tubes like the ones used in Callisto and Deimos are far stronger than the lightweight paper tubes used in low-power rockets, making them unsuitable for park flying. But fiberglass is heavier and stronger still. These rockets need to be treated with a great deal of respect. I don’t recommend them for beginning fliers. Wait until you have done a few flights, and can anticipate some of the inevitable failure modes of your rockets, before you start flying rockets built with fiberglass. A lot of fliers seem to be pretty cavalier about the risk of fiberglass rockets, but I think responsible fliers take the extra risk seriously, and plan their launch locations and who is present with great care.

That said, fiberglass is the material of choice from Mach 0.8 to about Mach 3.5, or perhaps a bit lower if the rocket stays at high speed for any length of time. It stands up to the heat and aerodynamic forces quite well. Once you have built and flown either Callisto or Deimos, I highly recommend building Phobos so you can get some experience with building a fiberglass rocket. It’s also a great first stage for the two-stage rocket we will build in *Make: Advanced High Power Rockets*. I’m not trying to scare you away from fiberglass, but I do think you should treat the safety issues with respect.

Cutting Fiberglass

Fiberglass is a wonderful material, and is widely used for boats, cars, airplanes, and rockets. Once it is in place, fiberglass is a very safe material. It does have some hazards when you are creating your rocket, though. Cutting or sanding fiberglass, especially with power tools, liberates a lot of very fine dust. This dust is really not pleasant stuff. It’s known to be a skin, eye, and lung irritant, and appears to be a lung carcinogen as well. This means you need physical protection when cutting and sanding fiberglass (see Figure 6-26).

Figure 6-26. Protective equipment for working with fiberglass includes gloves, safety goggles, a respirator, and something to cover your clothes.

The level of protection varies depending on what you are doing, of course. Let’s start with the worst case, which is sanding or cutting fiberglass with power tools. There are two kinds of protection you will need. The first is physical protection for your skin. I generally use dishwashing gloves for my hands. They are cheap, readily available, and cover your hands and lower arms. If you do not wear gloves, even hand sanding fiberglass might lead to a severe itch—that’s the small particles of fiberglass lodged in your skin. The dish gloves virtually eliminate this problem.

Some people wear coveralls in the shop, but most of us wear the same clothes we wear for everything else. You can kick up a lot of dust, though, and some of that gets into your clothes. If you think the light itching on your hands or arms from sanding is annoying, just picture dumping those clothes in the wash with your underwear. Covering yourself with something to keep the dust off of your clothes is a good idea. You can buy specialized covers specifically for working with hazardous materials. That probably makes sense if you are working with fiberglass on a daily basis. For only occasional projects, though, I’ve found that a cheap disposable rain poncho works great (see Figure 6-27). Safety glasses or goggles to prevent fiberglass particles from getting into your eyes are also a must.

The second kind of protection is for your lungs. You should have a good-quality respirator for all sorts of shop projects, from using some kinds of paint to using large amounts of epoxy. These can be found online and at most hardware stores. The problem is that there are several different kinds, and you need the right one. You will find some labeling on the package that indicates what the filter in the mask can remove from the air you are breathing. I recommend getting a mask labeled OV/AG/P100. This is a commonly available mask in hardware stores. P100 says the respirator removes particles, even really small ones or particles associated with oil, from the air. It is really all you need for sanding and cutting fiberglass, and even that is a bit of overkill. A mask rated N95, which means that it removes 95% of all oil-free particles, will actually do. OV stands for organic vapor. That will be important later, when you start making your own fiberglass parts. An OV filter removes the hazardous materials from paint and epoxy, which can also irritate your lungs. AG stands for acid gas, which we don't really need for working with fiberglass or epoxy. So, while you could start with a high-quality dust mask rated N95 or better, I recommend buying a slightly more expensive mask with at least OV/P100 protection, like the one I'm sporting in Figure 6-27. After all, it's your lungs we're talking about. You'll be living with them for the rest of your life.

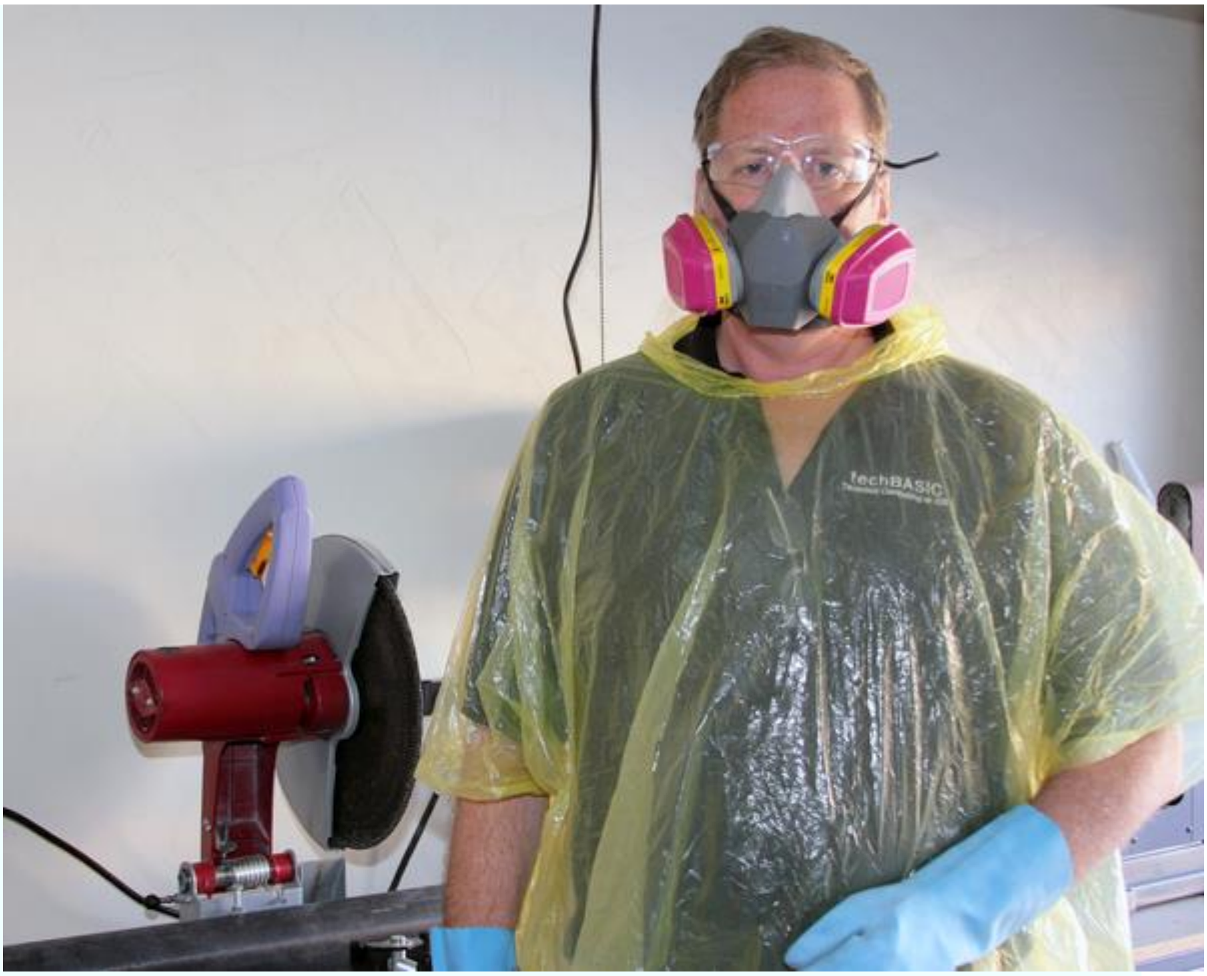


Figure 6-27. The height of fashion for working with fiberglass. Here the author is decked out in safety glasses, an OV/AG/P100 respirator, clothing protection, and hand protection. The hood of the poncho is generally up when sanding and cutting, but is down in the photo so the respirator is more visible.

I don't always wear all of this protective gear when working with fiberglass. I usually ditch everything but the gloves if I'm using hand tools or sanding by hand. You can use your own judgment based on what you are doing and how well your work area is ventilated.

Building Phobos

Phobos is very similar to Deimos, so I won't go into as much detail on building the rocket. Most of the instructions will concentrate on the differences between the rockets. All of the steps are here, though, so you can follow these instructions as a checklist. If something seems unclear, refer back to the Deimos instructions for a more detailed description of the various steps.

Phobos uses three G10 fiberglass fins (see Figure 6-28). The basic layout is identical to Deimos, but the fin tang will be shorter, since Phobos uses a larger motor mount tube than Deimos. You can cut them yourself, but as with the fins for Deimos, I think the easiest way option is to order three FIN-A-02 fins from PML.

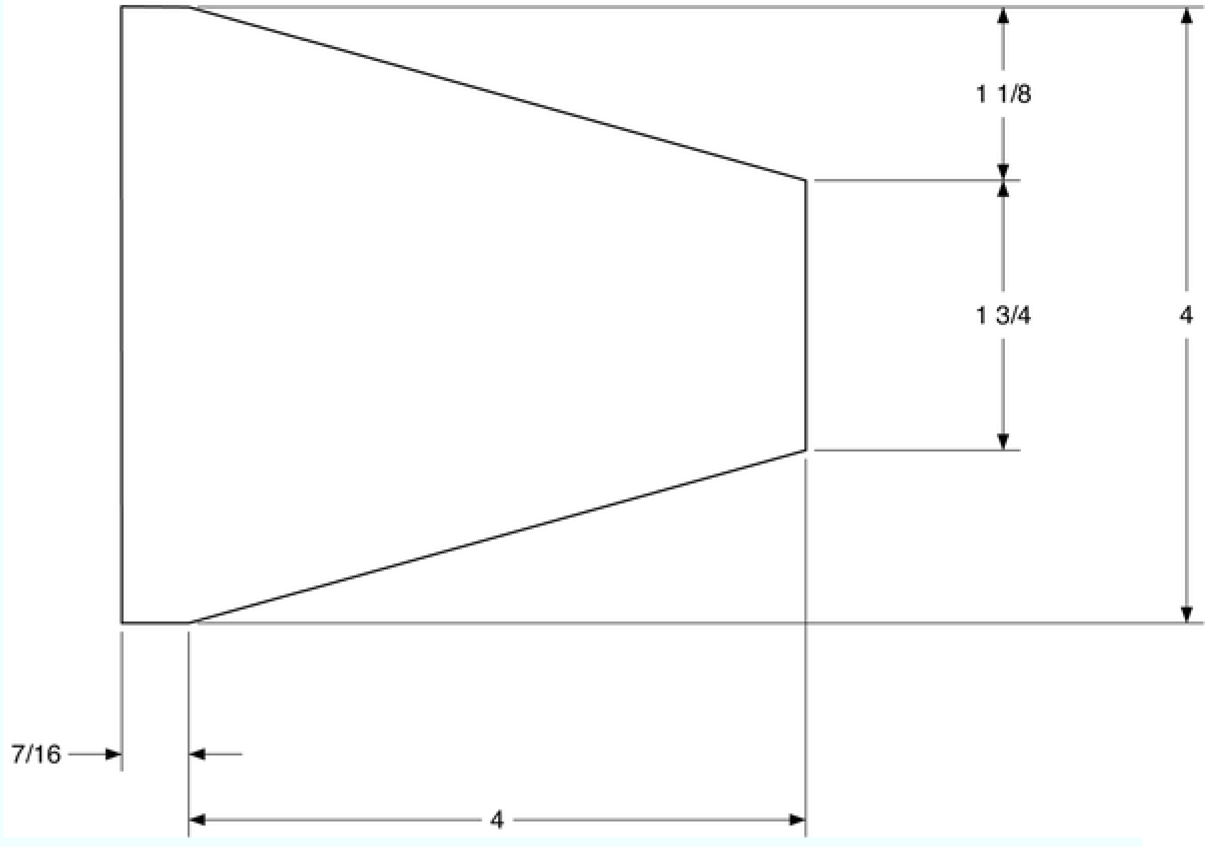


Figure 6-28. Cut three fins from 1/16" G10 fiberglass. You can order precut fins from PML.

You can use the same fin template you used to build Deimos. If you didn't build Deimos, make a fin template from a 12" square of corrugated cardboard. Put a 3" hole in the center, and then add three 4"-long 1/16" slots for the fins.

Wildman sells fiberglass body tubes by the foot. You will need two sections of airframe tubing, one 36" long and one 12" long. You can order two different pieces from Wildman, one 36" long and one 12" long, and probably get them cut to length that way. If you order a single 48" piece, or if it just comes that way, cut 12" from the overall length of tube. While most fine-toothed saws will work, I like to use a cutoff saw with a tile-cutting disk, as seen in Figure 6-29.

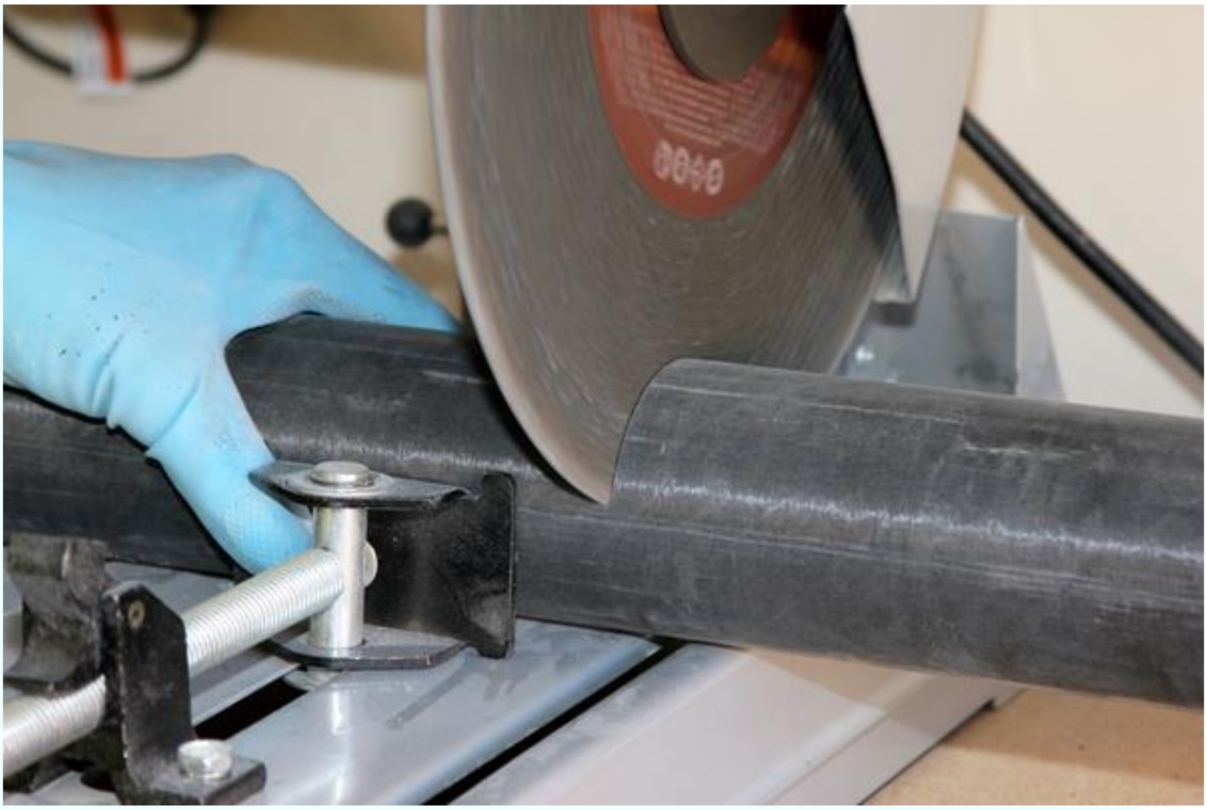


Figure 6-29. Cut two pieces of fiberglass body tube, one 36" long and one 12" long.

For reasons you'll see in a moment, it's convenient to build the payload section before the booster.

The Wildman FNC3INJ nose cone comes with five parts. While the website says the tip of the nose cone is phenolic, mine came with a metal tip, which is even better. This tip is held in place with an eye bolt and washer. There is also a tube coupler that forms the shoulder of the nose cone. Rough up the inside of the nose cone, and the outside of the portion of the tube coupler that fits into the nose cone, with medium grit sandpaper. Apply fast-drying epoxy to the inside of the base of the nose cone and slide the tube coupler into place (see Figure 6-30).

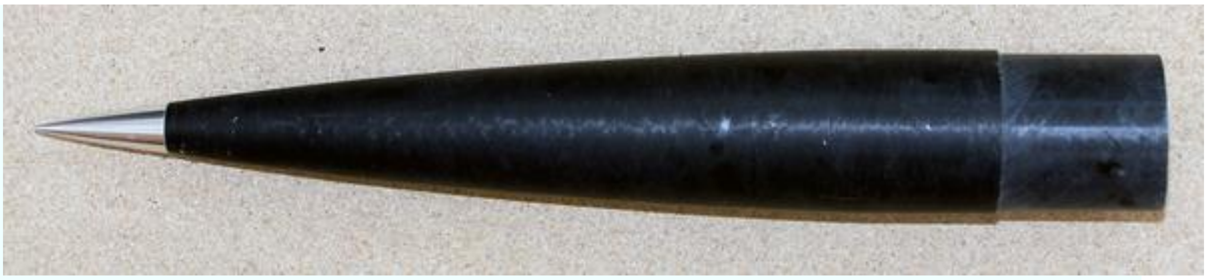


Figure 6-30. Rough up the inside of the nose cone and the outside of the tube coupler, and then glue the tube coupler into the nose cone.

Up to this point, we’ve been using eye bolts made from a twisted steel rod. These are quite strong, but real crashes with high-power rockets show that they are not strong enough in many situations. Phobos flies high enough and fast enough that there will be tremendous forces on the rocket if something goes wrong, and substantial forces even if things go right. We typically use closed eye bolts on larger rockets like Phobos. Wildman sells a welded stainless steel eye bolt. You can find similar eye bolts online and from other high-power rocket vendors. They are pretty rare at hardware stores, though, so order the eye bolt with the other rocket parts.

Figure 6-31 shows two eye bolts: one open and the other closed. The open bolt is on the left. It’s rated at 125 lb, which is certainly enough for a rocket like Callisto, and will do for a rocket like Deimos. The loop on the forged eye bolt on the right is made as a single piece. The difference in strength is staggering. The forged eye bolt is rated at 1,400 lb. Some of the difference comes down to the type of metal used. The open eye bolt is zinc-plated steel, while the forged eye bolt is stainless steel. If you have any experience with mechanical engineering, you also know that there are a lot of caveats to that simple strength number, but it does give us a starting place to compare two eye bolts that look fairly similar at first glance.

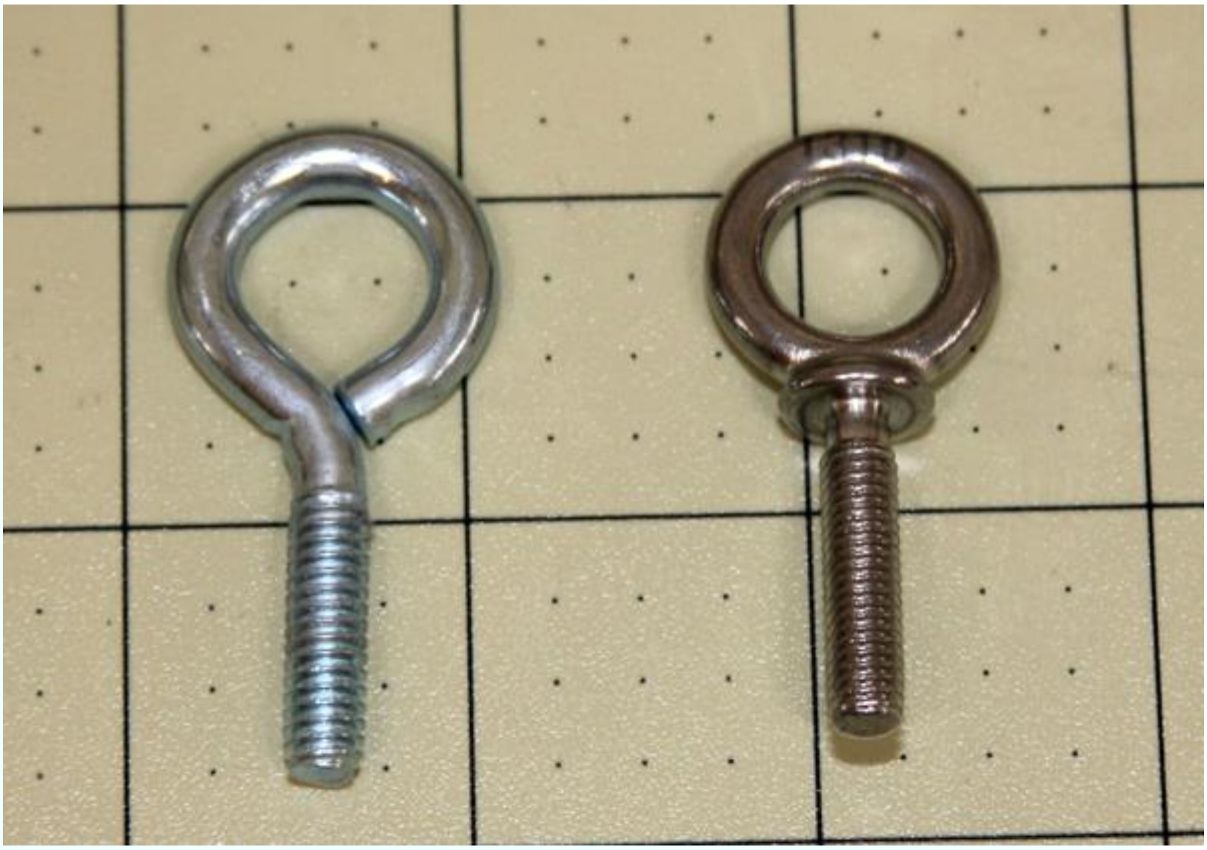


Figure 6-31. An open eye bolt on the left, and a forged eye bolt on the right.

The important thing when picking an eye bolt is not whether it is open or forged, though. What's important is the load rating for the bolt, which tells you how much force it can withstand. Keep in mind that this is not the weight of the components involved. You're not trying to hang the rocket like a display, you're trying to keep it together when a black powder charge blows the pieces apart, or worse, when it malfunctions and a parachute opens while the rocket is traveling at several hundred miles per hour. There is a lot of force on a rocket in those situations!

Wildman sells precut bulk plates that fit inside their airframes and tube couplers. Be sure to get FCBP3.0, which is for the tube coupler. Drill a hole to accommodate the eye bolt, then fasten the eye bolt in place. Be sure to use a washer to distribute the load. Add Loctite or a dab of epoxy to make sure the nut doesn't come loose.

Rough up the inside of one end of a 6”-long tube coupler with medium grit sandpaper. Use fast-drying epoxy to glue the bulk plate 1/4” from the end of the tube coupler. Add generous fillets on both sides of the bulk plate.

Rough up the inside of a 12” piece of airframe tube and the outside of the tube coupler. Each should be scuffed for about 3”. Spread fast-drying epoxy inside the airframe tube and insert the tube coupler so 3” of the tube coupler sticks out of the back end of the airframe (see Figure 6-32).

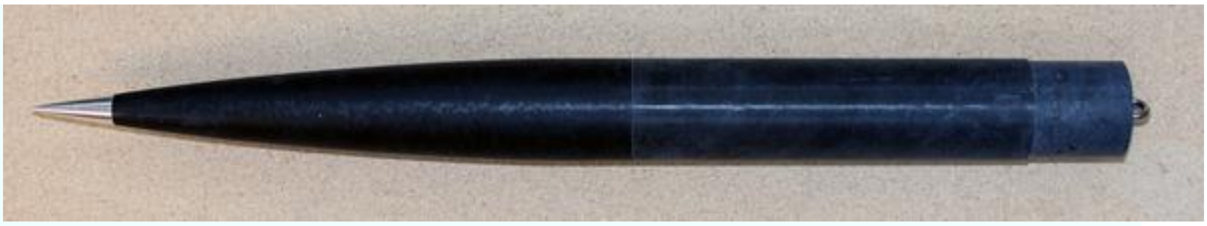


Figure 6-32. Fasten an eye bolt to a bulk plate. Roughing up all surfaces before gluing, glue the bulk plate 1/4" inside the tube coupler. Glue the tube coupler into the payload bay so 3" sticks out. Slide the nose cone into place to complete the payload section.

With the payload complete, let’s turn our attention to the booster. Make a fin guide from corrugated cardboard and mark the locations of the fins and rail buttons on the 36”-long body tube (see Figure 6-33). Use a piece of right angle aluminum to extend the fin lines about 5” along the body tube, and the rail button line along the entire length of the body tube.

The fins will be 1/2” from the bottom of the airframe tube. The root of each fin is 4” long. Mark the ends of the fin slots with horizontal marks 1/2” and 4 1/2” from the bottom of the body tube.

Mark the location for the aft rail button 2” from the base of the body tube. This is a slightly different location from Deimos, which was built so it could be used as the second stage of a two-stage rocket. Moving the rail button closer to the base of the rocket will make it a lot easier to install. As with Deimos, the forward rail button should be 5” from the front of the body tube.

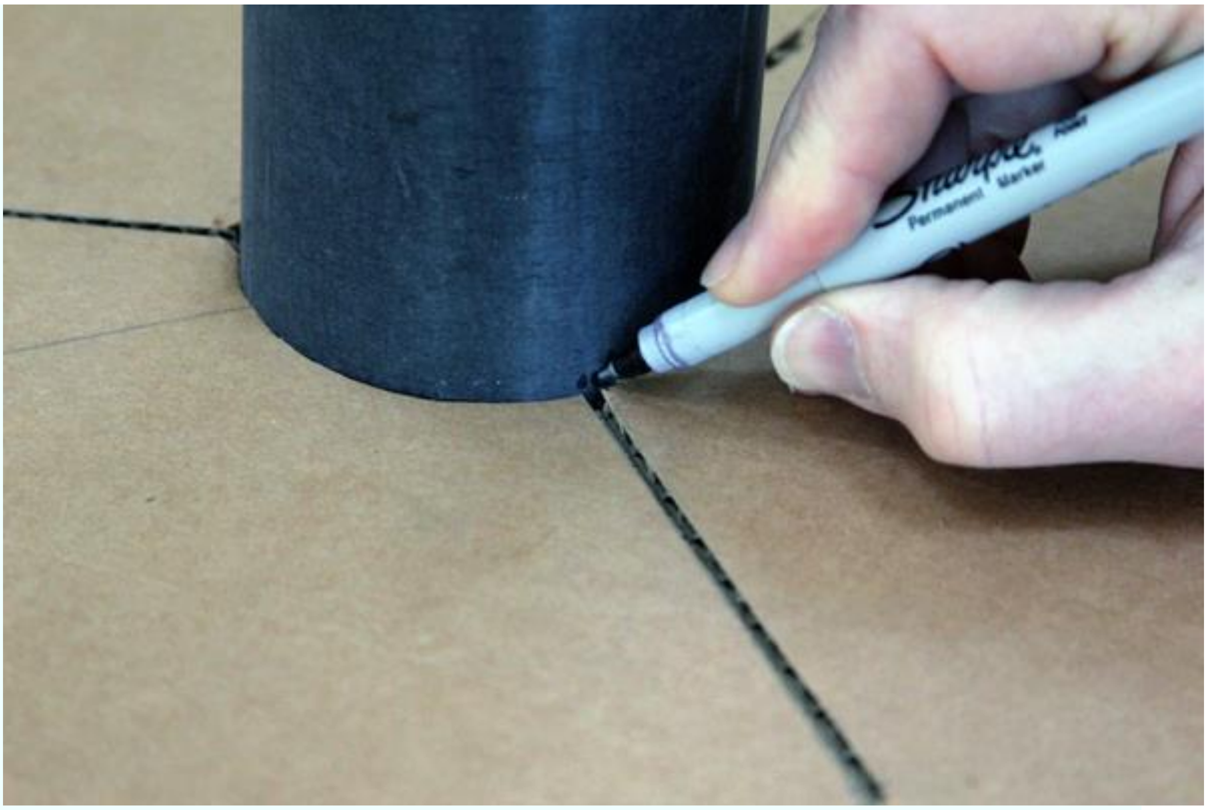


Figure 6-33. Use the fin guide to mark the fin and rail button lines, then extend the lines using a piece of right angle aluminum.

Wildman fiberglass tubes are black, as are all carbon fiber tubes I've seen. While you can see the lines from a black permanent marker if you look closely, it's pretty challenging to keep them in sight while cutting tubes. Add a strip of masking tape along one side of the fin line. This makes it very easy to see where you are supposed to cut (see Figure 6-34).

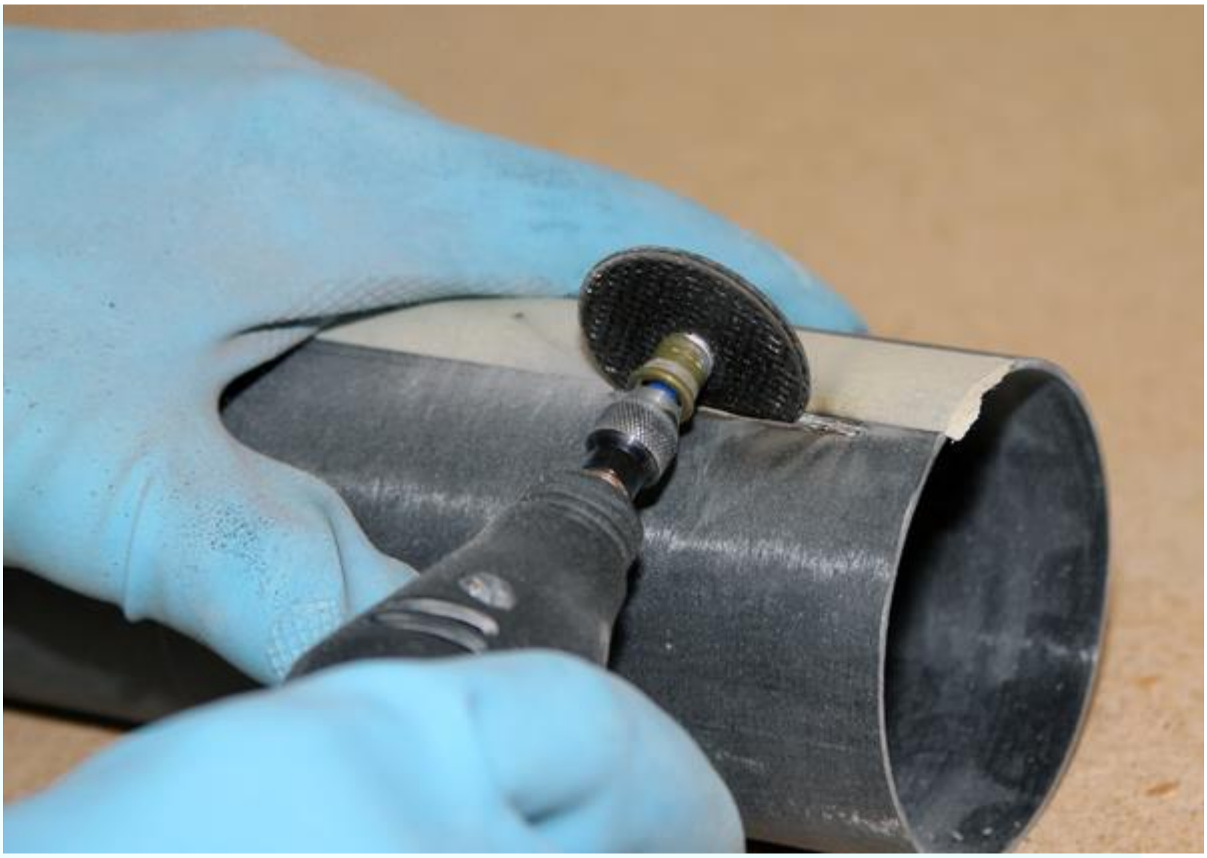


Figure 6-34. Add a strip of masking tape along one fin line to make it easier to see where you are cutting, then cut the three fin slots.

Stack enough cutting disks to match the thickness of the fins. Cut the fin slots, checking with a physical fin to make sure they are large enough.

Next, drill a 3/16” hole at the forward and rear rail button locations.

On some motors, Phobos can travel 2 miles high in a little over 20 seconds. This creates a unique problem we really haven’t seen up to this point. The air up there is thinner than at the launch pad; in rough numbers, about 40% thinner. Air pressure at sea level is 14.7 lb/in^2, so the difference after losing 40% of the air is about 5.9 lb/in^2. The base of the payload section has a diameter of 3”, so the area is 7.1 in^2. Putting all that together, our rocket will have around 42 lb of force trying to push the payload section out of the main body tube, and that’s before we set off the black powder charges to deploy the parachute! That can, and frequently does, cause rockets to separate early. This can cause catastrophic failure of a rocket if it happens while the rocket is traveling at high speed. That just won’t do.

For a high, fast flier like Phobos, we need to do two things to prevent the rocket from popping apart early. The first is to add some vent holes in the booster section. We'll also add them to the payload section so any altimeters we add will be able to get an accurate reading of the air pressure. Add three 1/8" holes 6" from the front of the booster airframe tube, evenly spaced around the circumference. Remember to use gloves for protection, as seen in Figure 6-35. Add three more 1/8" holes 4" from the base of the payload airframe tube, again spacing them evenly around the tube.

The other thing we'll do is add shear pins to hold the rocket together. There are many different kinds of shear pin. I like to use 1/16"-diameter polystyrene rods. You can find these at hobby stores that specialize in trains and airplanes. They will have a display with various-sized rods, tubes, and squares of plastic. You can also buy shear pins from most high-power rocket companies, including Wildman (navigate to the Building Materials section of the website and you'll find the pins in the Miscellaneous category). You should wait to drill these holes until the payload section is glued together, though.

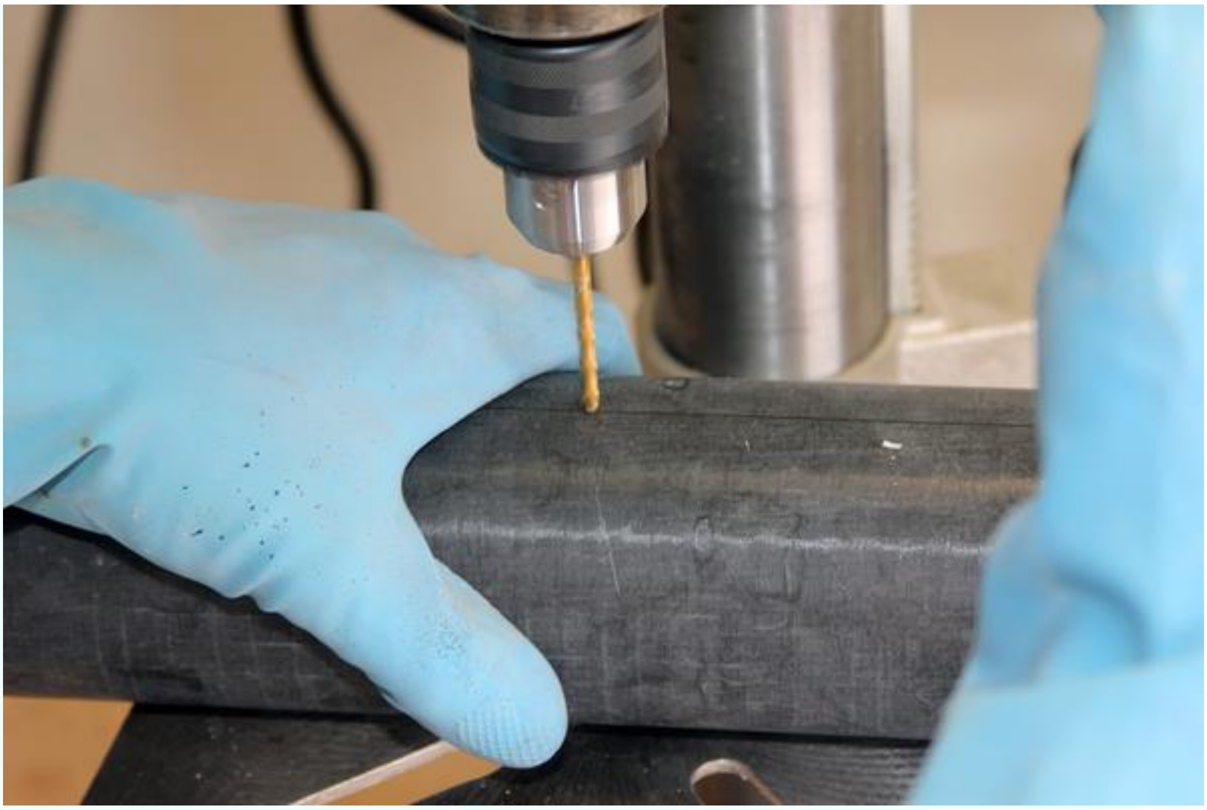


Figure 6-35. Drill holes for the rail buttons, vent holes in both the booster and payload bays, holes for the screws that hold the nose cone in place, and holes for the shear pins.

Slide the payload section into the booster airframe tube. Assuming you are using 1/16” polystyrene rods for shear pins, drill three 1/16” holes 1 1/2” from the end of the booster, so the drill goes through both the booster and the tube coupler at the base of the payload bay. Space the holes evenly around the airframe.

Finally, drill three pilot holes for 1/2”-long #4 pan head screws 1 1/2” from the top of the payload tube, drilling through the airframe and the tube coupler that forms the shoulder of the nose cone.

Use 20 feet of 9/16” tubular nylon for the shock cord.

Cut a notch on the inside edge of one of the two centering rings that will hold the motor mount in place. The notch should be just large enough so you can slide the shock cord through the centering ring, as seen in Figure 6-36. Use medium grit sandpaper to scuff the top and bottom of both centering rings so the epoxy will bind well to the parts.

The motor tube in the parts list is a 24”-long, 54 mm”diameter fiberglass tube. Wildman sells this as G12-2.1, since 54 mm is also 2.1”. You don’t have to use a fiberglass tube for the motor mount, though. It won’t be subjected to the same heat and aerodynamic forces as the airframe; a phenolic tube is much less expensive and will work just fine. Still, most people use a fiberglass motor tube for a fiberglass rocket.

Rough up the outside of the motor tube with medium grit sandpaper, then glue the shock cord and centering ring in place with fast-drying epoxy. The centering ring should be 1/2” from the end of the motor mount. Wrap the shock cord around the motor mount twice for a secure fit, as shown in Figure 6-36. Be sure to soak the shock cord in the epoxy, getting plenty between the tube and shock cord, as well as covering the shock cord on the top and sides. You are essentially creating a single piece of material, with the inside portion consisting of resin and fiberglass while the outside portion is resin and nylon.

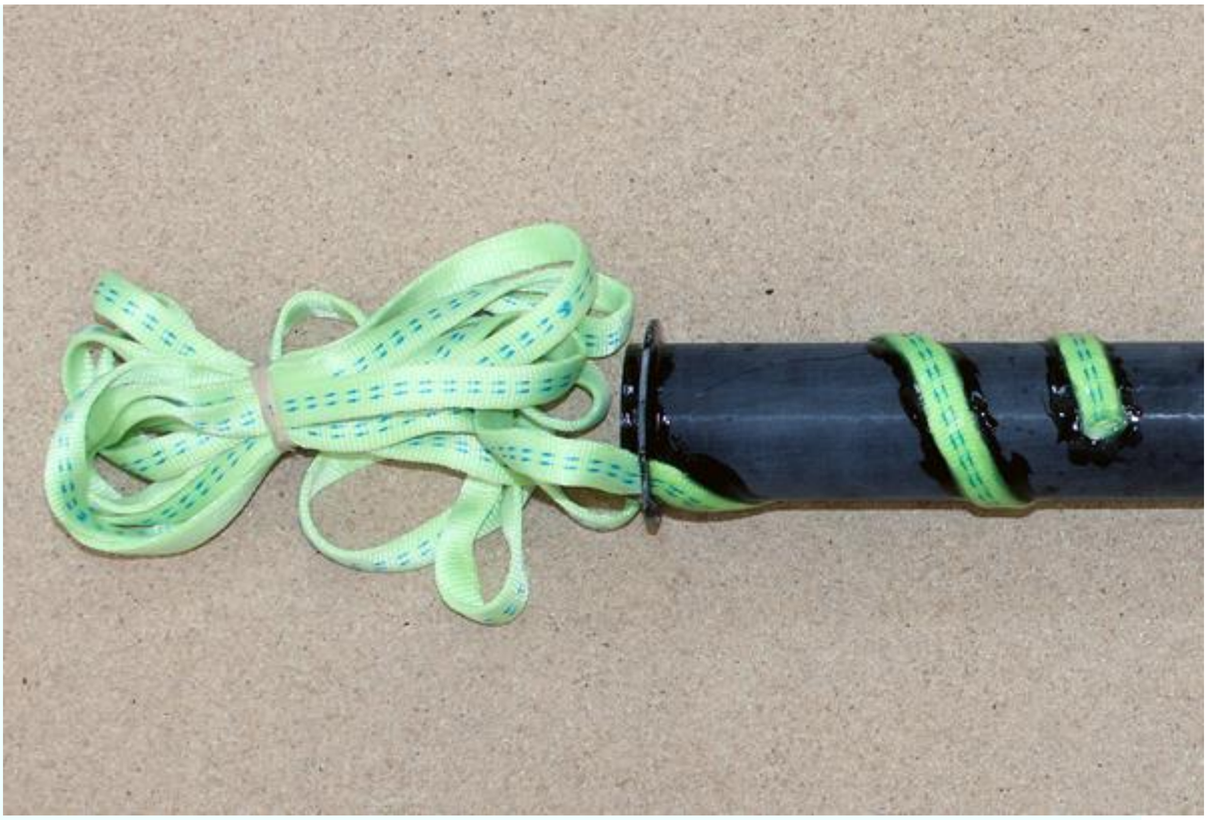


Figure 6-36. Cut a notch in the forward centering ring large enough for the shock cord, then glue the centering ring and shuck cord in place.

Apply generous epoxy fillets to the top and bottom of the joint between the motor tube and centering ring.

Cut a 2-foot-long piece of 1/4”-diameter Nomex tube to cover the portion of the shock cord that will be closest to the ejection charge. Slide it into place at the base of the shock cord, right next to the centering ring.

Attach two quick links to the shock cord, one 1/3 of the way from the loose end, and the other at the end. You will use these to attach the parachute and payload bay.

Scuff the areas on the inside of the body tube that will be glued, including the areas where the rail buttons and fins will be glued. Scuff the outside of the tube where the glue fillets will attach, too. Glue the forward centering ring of the motor mount in place, using the aft centering ring to make sure the tubes are in perfect alignment. Use dental floss around the aft centering ring so you can remove it before gluing the fins in place (see Figure 6-37).

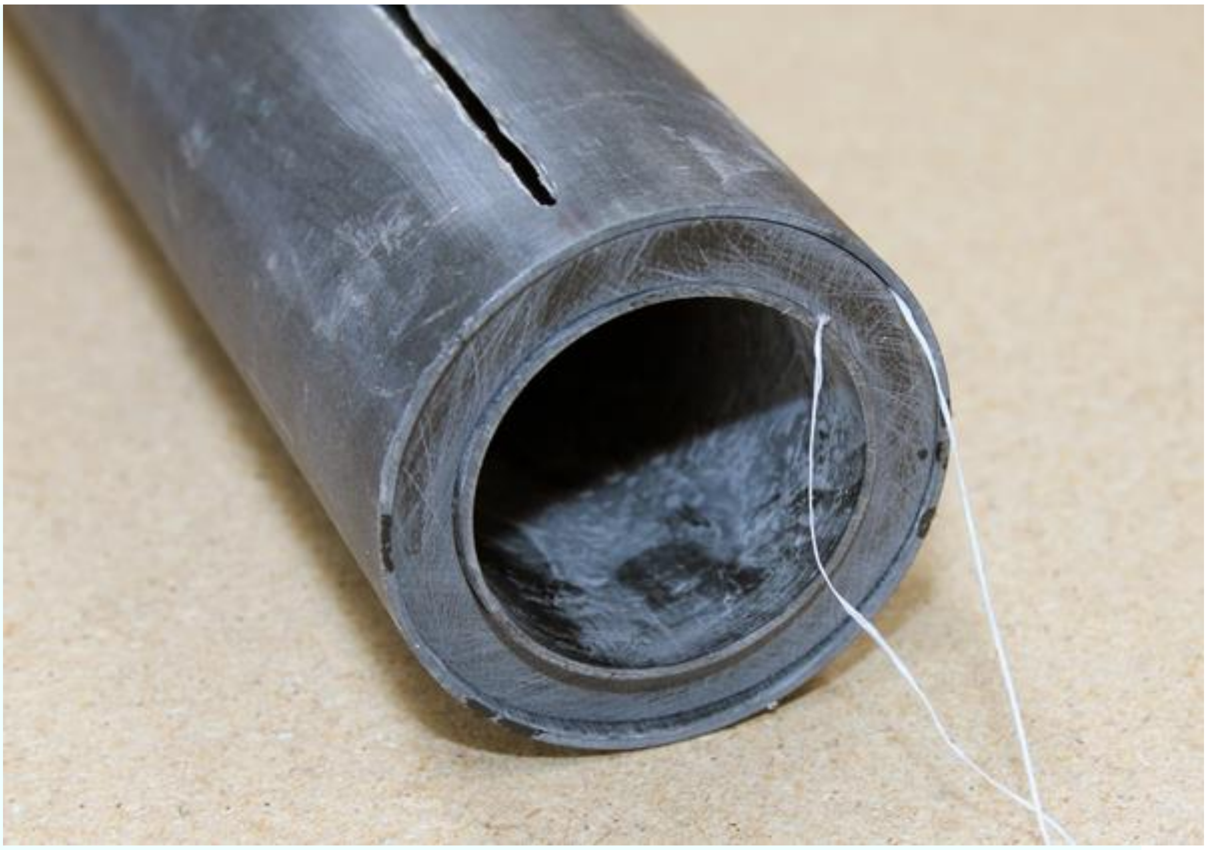


Figure 6-37. Glue the forward centering ring in place, using the aft centering ring to guarantee perfect alignment. Notice that the centering ring and fin slot have been roughened with sandpaper so the glue holds better.

This is a fairly heavy rocket with parts that are a lot more rigid than paper or plastic. These rockets have a tendency to pop the fins loose from the motor mount if they have a hard landing, so I’ve become a firm believer in really strong internal fillets for all fiberglass rockets. Figure 6-38 shows the massive fillets for Phobos.

The fillets on the exterior were formed using slow-cure epoxy applied with a popsicle stick, just like the ones on Callisto and Deimos. The internal fillets, though, were formed by mixing an epoxy filler with the glue. This paste was applied so the filler is about as thick as the gap between the motor tube and airframe tube. I used West System 403 Microfibers Adhesive Filler for the filler, but there are several kinds available, and all will work fine. Be sure to experiment with the filler a bit before you start, to get familiar with its characteristics. The filler will speed up the curing time for the epoxy. Even with slow-curing epoxy, the curing time can be rather quick. You need to be ready for that, and get the paste into place quickly.

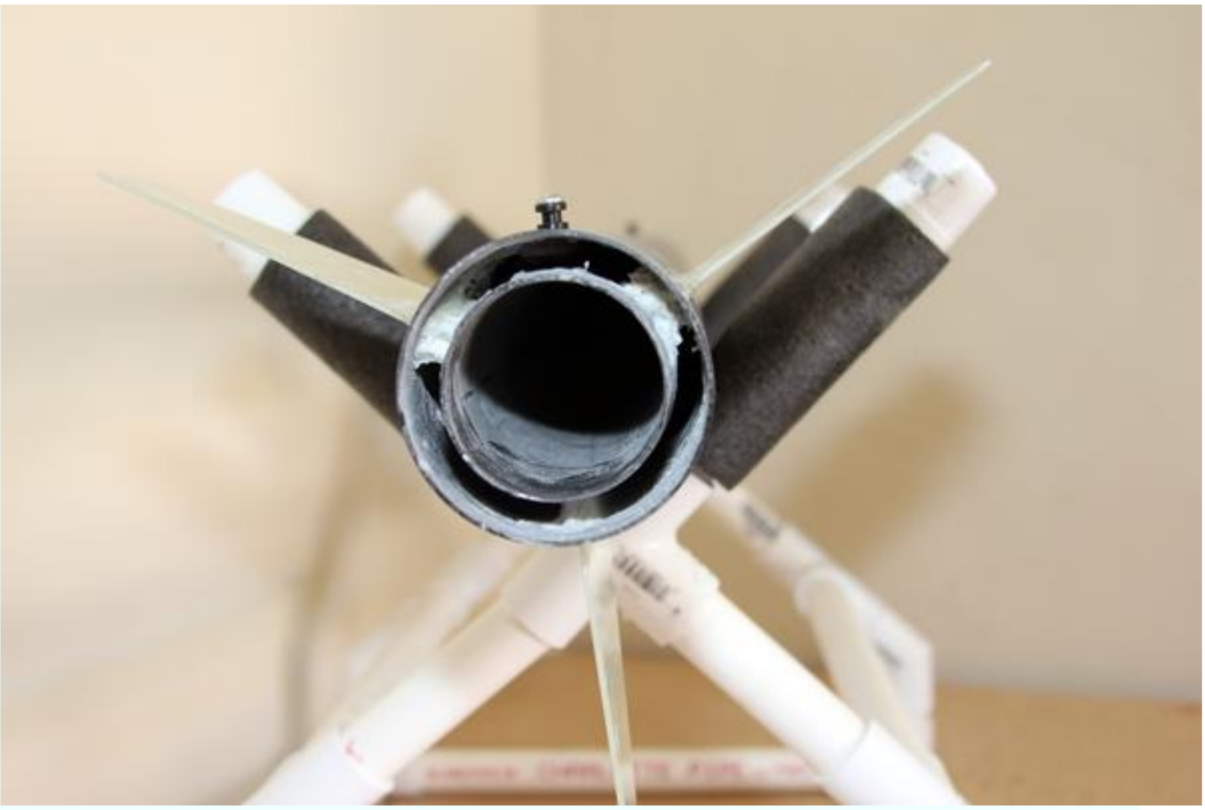


Figure 6-38. Glue the fins in place, add the fin fillets, and attach the aft rail button.

You might think these fillets are excessive. I've known flyers who literally pour epoxy into the fin can, filling the entire gap with solid resin. While I don't go to that extreme, I can't fault them—I have snapped the thinner fillets on fiberglass rockets, though.

Tack the fins in place using slow-cure epoxy. Use your fin guides to hold the fins in place while the glue sets. Refer back to Figure 6-17 if you don't remember how that is done.

Apply fillets to the fins, being very generous with the fillets on the inside of the airframe.

Attach the aft rail button, gluing the rail button nut in place. Be sure you only glue the nut in place, not the rail button screw, so you can remove the rail button for painting or to replace a worn button. You can attach the forward rail button, too, but I generally don't glue that nut into place. You will need to remove it later for painting, of course.

Glue the aft centering ring in place, applying a generous fillet around the outside edge where it meets the airframe tube, but not to the inside edge. Make sure the centering ring is pushed in far enough so the motor retainer will slide onto the motor tube.

Use a heat-resistant epoxy like JB Weld to attach a motor retainer to the motor tube (Figure 6-39).

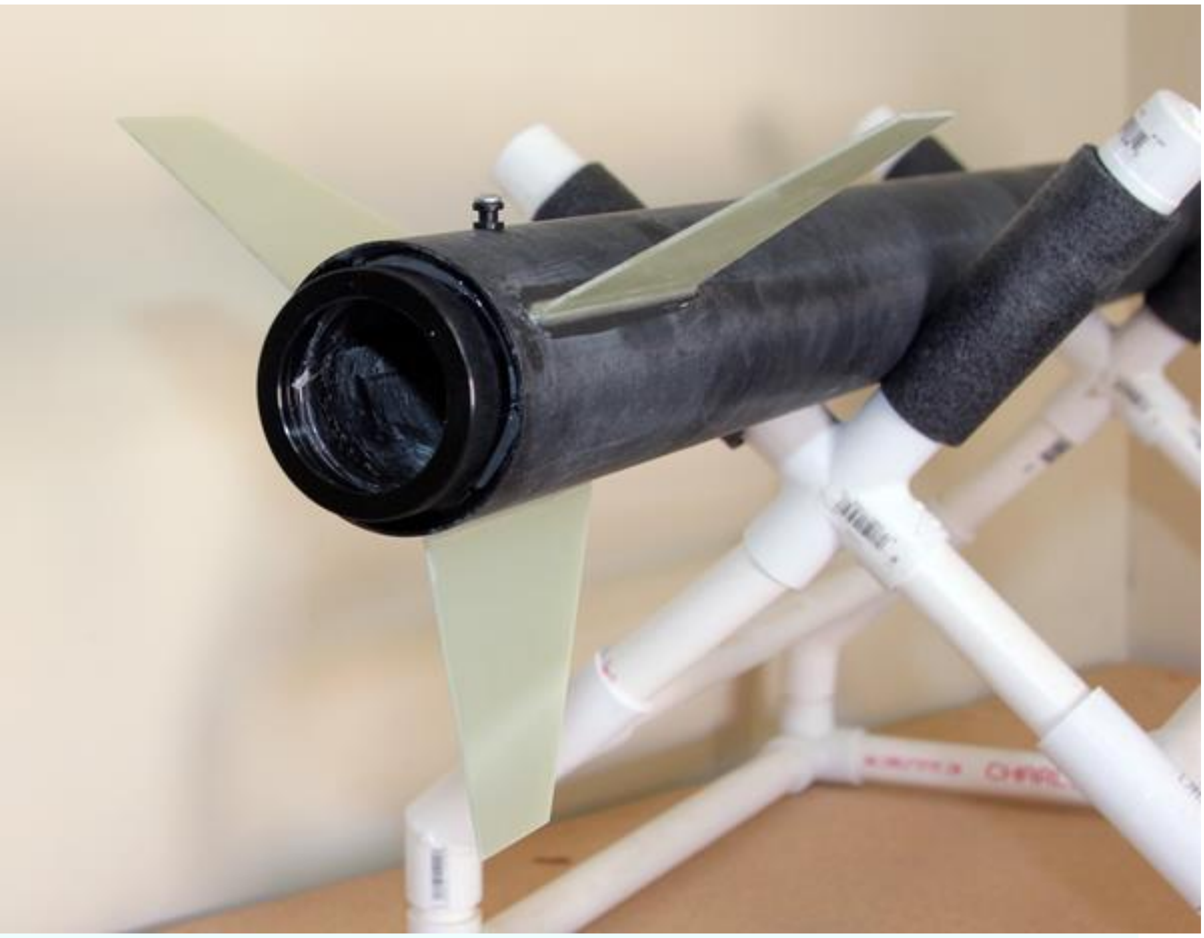


Figure 6-39. Glue the aft centering ring and motor retainer in place.

That finishes the construction for Phobos (see Figure 6-40). Remove any remaining slick, shiny parts of the epoxy with fine sandpaper, and then paint the rocket.

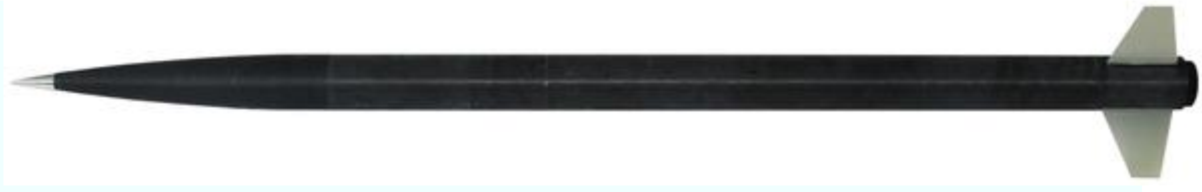


Figure 6-40. Phobos is ready for paint.

Flying Deimos and Phobos Using Single Deployment

As I mentioned earlier in the chapter, I would not recommend flying either rocket on a J motor for your Level 2 certification without dual deployment and a tracker. That said, both rockets fly well on smaller motors using single deployment, just as you used for Callisto. The only difference between flying Deimos and Phobos is the size of the parachute. Deimos can get by with a 48” parachute, but the heavier Phobos really needs a 50”–60” parachute, depending on the motor size.

Motor Adapters

One issue will pop up right away, though. The smaller motors are too small to fit in the motor mounts for these rockets. That means you need a motor adapter.

There are a lot of alternatives when it comes to motor adapters. One of the easiest to use is the HAMR system from PML. Figure 6-41 shows the 54/38 adapter, catalog number ADPTR-54/38-HAMR. It’s mounted on an AeroTech 38/360. An I218R-10 reload in this motor case would take Phobos to about 1,500 feet, which is a nice comfortable altitude for a single-deployment flight. If you decide to give it a try, follow the flight preparation instructions for Callisto. The procedures for flying Deimos and Phobos with a parachute using single deployment are exactly the same as for flying Callisto.

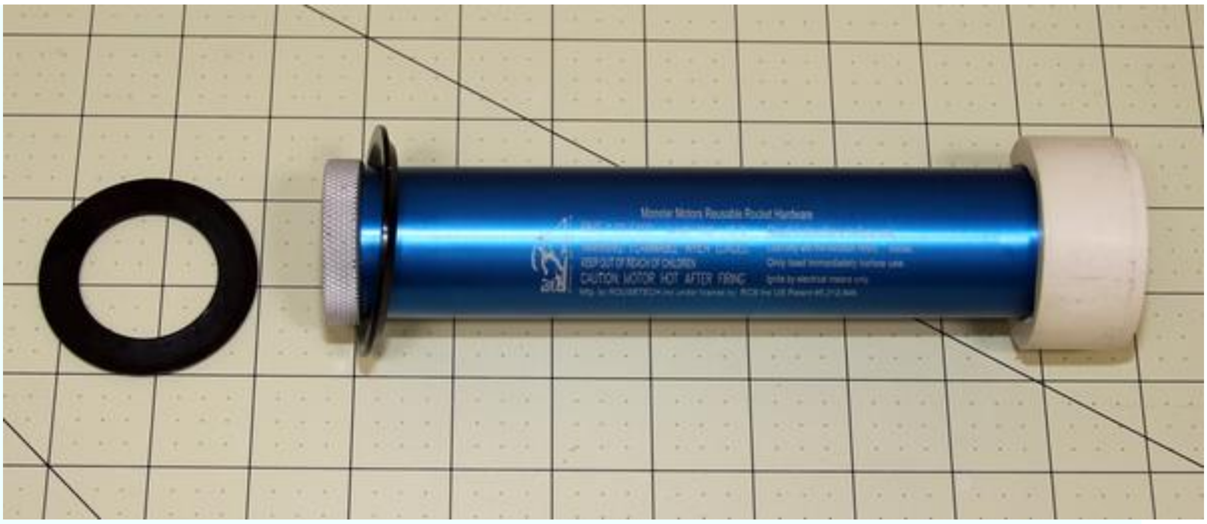

Monster Motors Reusable Rocket Hardware
WARNING: FLAMMABLE WHEN LOADED
KEEP OUT OF REACH OF CHILDREN
CAUTION: MOTOR HOT AFTER FIRING
Only load immediately before use
Ignite by electrical means only

Figure 6-41. The HAMR adapters from PML are quick and easy to use.

The HAMR system comes in three sizes. In addition to the 54/38 shown, you can use a 54/29 adapter to fly 29 mm motors in Phobos, or the 38/29 adapter to fly 38 mm motors in Deimos. The Level 3 rockets shown later in the book use 75 mm motor mounts, though, and there is no HAMR adapter for motors that large. Fortunately, it's pretty easy to make your own. The scratch-built adapter shown in Figure 6-42 uses a 38 mm motor tube, several handmade centering rings cut from 1/4" aircraft plywood, a standard 38 mm motor retainer, and an eye bolt for attaching the shock cord. The point here is that you can make your own motor adapters for any situation using the same techniques you have learned for building rockets.

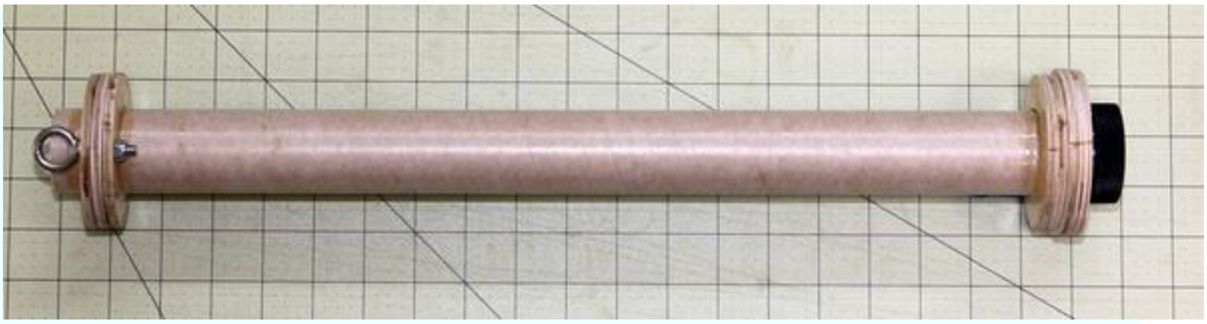


Figure 6-42. This 75/38 adapter is scratch built using the same parts and techniques you have learned for rocket construction.

What About the Shear Pins?

We built Phobos to handle shear pins because it could go so high and fast on a 54 mm motor. What do you do about those on these smaller motors?

The easy answer is to ignore them. The shear pins aren’t needed unless you’re stuffing a large 54 mm motor into Phobos. If you’re doing that, you really should be using dual deployment and a tracker. We’ll discuss shear pins when we cover dual deployment.

That doesn’t mean you can’t use shear pins with a smaller motor. If you want to give them a try with a single-deploy motor, read “Shear Pins” to see how they are used.

Now that you have a basic Level 2 rocket, it’s time to get it ready for your Level 2 flight! The next few chapters will cover various changes you can make to the rockets. Chapter 11 covers the Level 2 exam.

Chapter 7. Altimeters and Dual Deploy with Cable Cutters

Rockets that fly high have a problem. They need to touch down softly, to protect both the rocket and the things it might land on. At the same time, a moderate crosswind can easily carry the rocket as far away from the pad as the altitude it reached. That's fine when it's a model rocket that goes to 1,000 feet, but not so acceptable when it's a high-power rocket that soars to 15,000 feet—about 3 miles!

This chapter shows the first way to solve the problem. The rocket pops the parachute at apogee, but the parachute is secured with a zip tie. The rocket falls quickly to about 500–1,000 feet, where a barometric pressure sensor fires a cable cutter that cuts the zip tie, allowing the parachute to open for a soft landing. The chapter includes detailed instructions for modifying the Level 2 rocket for dual deployment, including flight preparation. You can use the same technique for modifying practically any other high-power rocket. Along the way, we'll cover altimeters, shear pins, and black powder ejection charges.

Keep in mind that this is just one way to handle dual deployment. We'll turn to the classic two-bay solution in the next chapter.

What Is Dual Deploy?

Most high-power rockets that fly over 2,000 feet high use an electronic altimeter. These altimeters are not really there to tell you how high your rocket went, although they certainly do that, too. Their real purpose is twofold.

First, a timed ejection charge works fairly well, but it's almost never the *perfect* length of time. Smoke charge–based ejection is also not the most reliable way to time the ejection event. Don't get me wrong—it's good enough for almost any purpose, but it is not perfect. An altimeter does a much better job. The altimeter can detect when the rocket gets to apogee, where its vertical motion stops completely. Assuming the rocket has not arced over too much due to wind or poor construction, it’s also traveling at a very slow speed. This makes apogee the perfect time to pop out the parachute. Altimeters used in high-power rockets do just that, usually by firing a small black powder charge that replaces the ejection charge built into some motors. The altimeter itself supplies a voltage to an igniter, which is stuffed into the black powder.

However, as mentioned in the introduction to the previous chapter, popping out a parachute at apogee is not the best solution if the rocket is traveling very high. Let’s say your parachute will bring the rocket down at a nice, stately 12 ft/s. That’s at the low end of the recommended descent rate, but it’s a good speed for a large rocket. Perhaps your rocket is flying to an altitude of 5,000 feet, which is not hard to do with the Level 2 rockets from Chapter 6. With those parameters, your rocket will take almost 7 minutes to descend to the ground! While it’s descending, it will drift in the wind. If you are flying on even a moderately windy day, with perhaps 10 mph winds, the rocket will drift 1.15 miles—a little more than the altitude it reached. Of course, if the wind is twice that strong, your rocket will drift twice as far. After a few flights, you will also realize that the wind speed aloft is often rather different from the wind speed on the ground; you might lift off in a very light breeze of 5 mph, expecting a leisurely half-mile walk for your recovery, only to have your rocket get caught in a fast-moving stream of air at 3,000 feet and drift out of sight!

Of course, you will probably have some sort of tracker on the rocket, so finding it may not be a problem. Still, you might bust the FAA waiver. Keep in mind that the FAA waiver is not just for altitude; it actually covers an area in the shape of a cylinder with a maximum altitude and a maximum distance from the pad. Busting the waiver could land both you and the club in the FAA’s bad graces, which would, at the very least, make you rather unpopular in your rocket club. Even if you don’t bust the FAA waiver, the rocket might drift into an area where it does some harm when it lands, or it might land somewhere that makes it difficult to recover.

Most altimeters offer a way to deal with this issue. They can fire an event at a specific altitude, usually 500–1,000 ft. With an altimeter, you can program your rocket to free fall from apogee to this lower altitude, and then open the parachute.

But of course, it’s never that simple. If you allow the rocket to descend ballistically, it will be going pretty fast when the parachute pops open. The shock of deployment when a rocket is traveling at high speed can easily rip the parachute to shreds, pull the shock cord through the body tube, or rip out a bulkhead. I’ve seen every one of those things happen in real flights (see Figures 7-1 and 7-2). Pulling a shock cord through a body tube is a common enough occurrence that it even has a name among rocketeers; it’s called a zipper.

Figure 7-1. It may be called rip-stop nylon, but parachutes are not indestructible. This 48" chute ejected at about 100 ft/s.

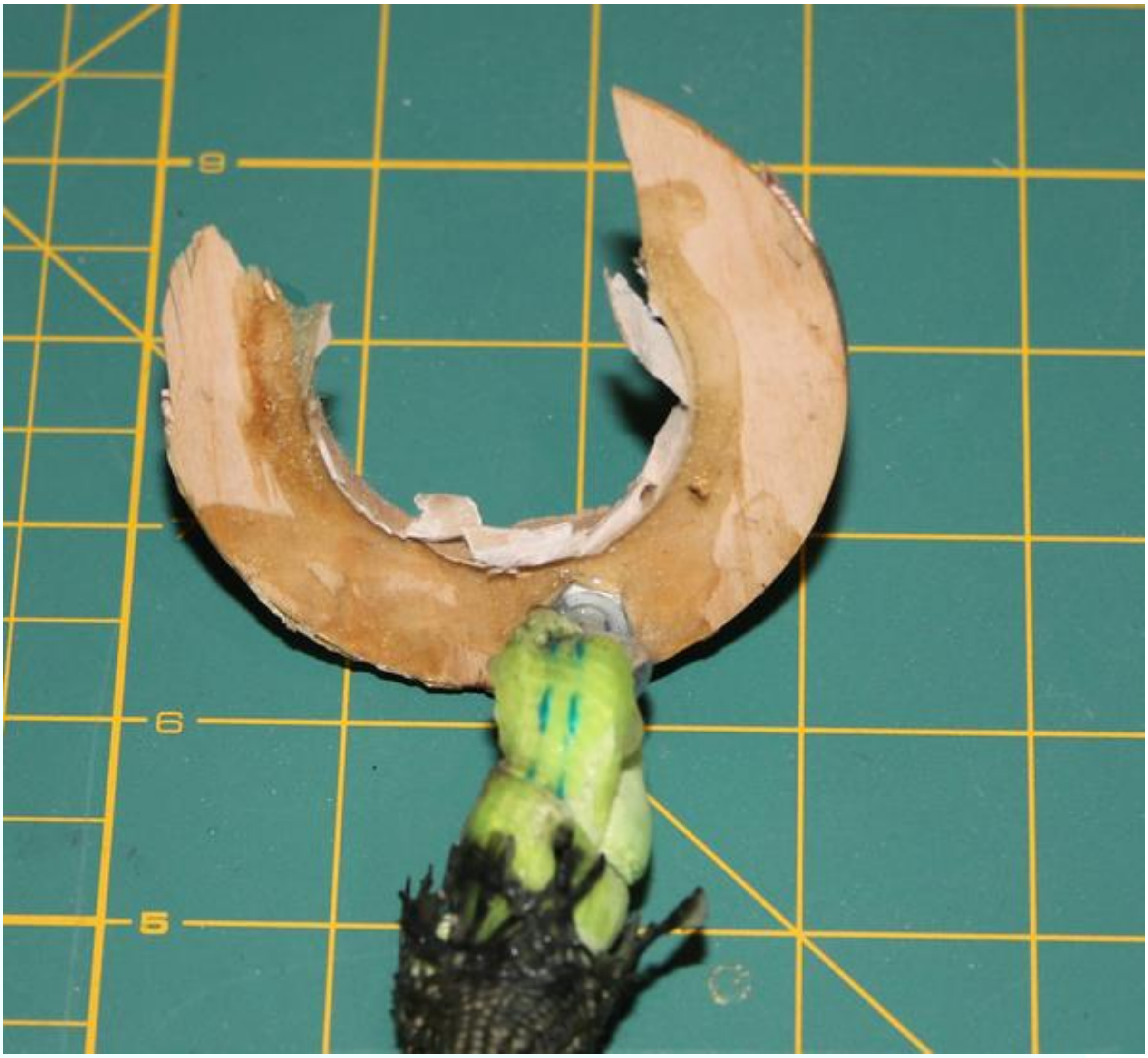


Figure 7-2. This bulkhead was also pulled out of the rocket on the same flight that ripped the parachute.

The solution is called *dual deployment*. Rather than open a large parachute at apogee, we opening something much smaller. Depending on the size of the rocket and the preference of the flier, this *apogee event*, also sometimes called the *drogue event*, might deploy a small parachute, a streamer, or nothing at all. Just popping the rocket apart so it tumbles is actually more than sufficient for a medium-sized rocket. Only when the rocket gets to a lower altitude does the second event fire, opening the main parachute for a soft touchdown. This is called the *main event*, since it is the main parachute that is deployed.

There are a number of ways to build a rocket for dual deployment. We’ll look at two in detail. The method shown in this chapter uses a cable cutter. The main parachute is ejected at apogee, but it is held closed using a zip tie. The bundled parachute acts as a streamer during the first part of the descent. When the rocket gets to a lower altitude, the main event fires a device that cuts the zip tie, allowing the parachute to open. You can use a small parachute or streamer, too, but for Deimos or Phobos, using the main parachute wrapped in a zip tie as a streamer works just fine. The advantage of this method is that you can adapt practically any rocket to use dual deployment with a cable cutter, even one that has already been built and flown. The only requirement is a payload bay large enough to hold the computer. Even a hollow nose cone is usually big enough to house a computer.

The second common method uses two parachutes, almost always packed in two different parachute bays. The first parachute is called the *drogue parachute*, and it is the one that opens at apogee. This is usually a very small parachute. We’ll use a 12” parachute for Deimos and a 24” parachute for Phobos, which is a bit heavier. The main parachute opens at a lower altitude, returning the rocket with two parachutes. We’ll see how to adapt Deimos or Phobos for a drogue and main in the next chapter.

Choosing an Altimeter

Modern high-power rocket altimeters are small, relatively cheap, and very reliable when used properly (see Figure 7-3). They have a small onboard microcontroller that gathers data from onboard instruments. You might think that they would use an accelerometer to figure out the altitude, but it turns out that just isn’t the best method. Most computers use a sensitive barometer to find the altitude of a rocket. Early high-power rocket altimeters would sometimes misfire due to uneven pressure distribution as the supersonic shock wave passed over the ports that allowed air in and out of the altimeter chamber, but this is a problem that is pretty well understood and compensated for now. Some computers use accelerometers as a secondary altimeter, often to prevent those shock waves from tricking the computer. The accelerometer is also used for launch detection. That prevents a stray gust of wind across the barometer’s port from tricking the rocket into thinking it took off, which might cause early deployment of a parachute. Rocketeers often look at altimeter data to get an idea about the forces on their rockets, particularly vibrations. Altimeters occasionally have gyroscopes, although this is a feature that seems to come and go.

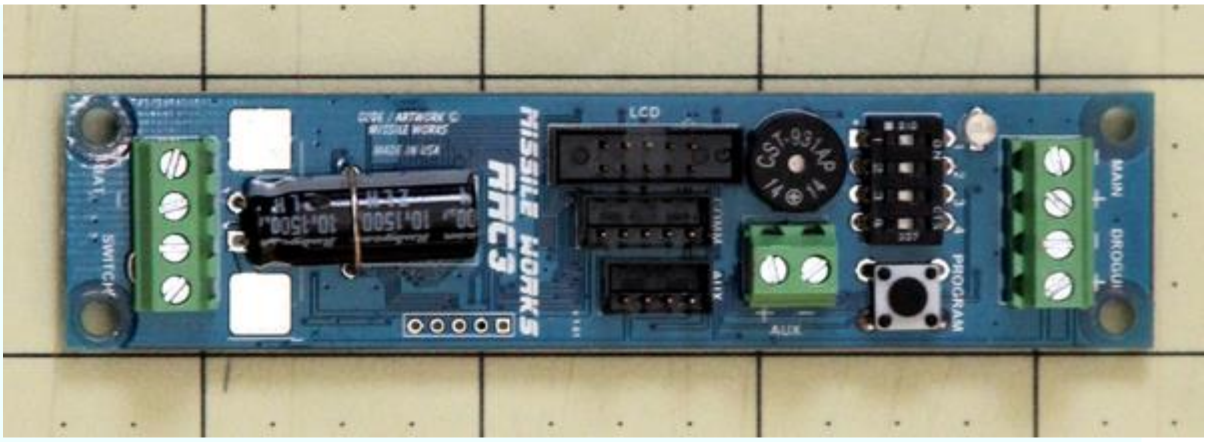


Figure 7-3. The Missile Works RRC3 is a fairly typical flight computer. We'll examine it in more detail later. For scale, the grid marks on the cutting board are 1" apart.

Altimeters have a fairly wide variety of feature sets. Let's take a look at some of the features that are available, and then look at a few specific altimeters.

Altimeter or Computer?

Most people call the device we're talking about an *altimeter*, and I will, too, when discussing the part. It's a bit of a misnomer when discussing all of the features packed onto these amazing devices, though, since they are so much more than altimeters. Really, they are special-purpose computers that use sensors to control your rocket. That's why I will call the device a *flight computer* when talking about the various features.

The basic function of a flight computer is to open a parachute. In almost all cases, this happens when the flight computer decides the situation is right for an event to occur. The computer sends an electric signal to whatever device you decide, usually an igniter that sets off a black powder charge to eject a parachute. Most flight computers can generate two distinct signals, the apogee event and a main event. The apogee event fires when the rocket reaches its highest point and starts back down. The main event occurs at a predetermined altitude, typically 500 to 1,000 feet, and only occurs on the way down, not on the way up. This is the minimum feature set you should look for on any flight computer. With the exception of a few very small altimeters designed for low-power rocketry, all of the modern flight computers will have this basic functionality.

There are often other events you might want to fire, though. A great example is a two-stage rocket. The second stage will usually fire a total of four events. The first two are the familiar apogee and main events. Another is stage separation, which is often done with a black powder charge that fires to separate the two parts of the rocket. The fourth event is to light the second stage motor itself. A basic flight computer will support two events; more sophisticated computers will support several, along with some means of programming the computer to choose when those events fire.

Face it, people are naturally curious. One of the first questions spectators ask us about our rocket flights is how high they went. It’s one of the first things we want to know, too. Almost all flight computers can report the maximum altitude. They typically do this with a series of beeps, occasionally backed up by flashing an LED, so you know how high the rocket went as soon as you find it. A few even have a radio transmitter, and will broadcast the altitude back to a ground computer in real time.

After the flight, we generally want to look at the details. Many flight computers let you download the data from the flight. Sophisticated software tells you things like the maximum speed, perhaps so you can verify that your rocket really broke the sound barrier. You can look at descent speed to see if your parachute was big enough. Most report battery level, which varies quite a lot as the ejection charges fire.

You can use a lot of different kinds of batteries to power a flight computer. The most common is a 9-volt alkaline battery. These are sufficient for firing most igniters, including electric matches and the Quest Q2G2 igniters, both popular choices for firing black powder charges. If you are lighting an igniter for a multi-stage rocket or an air start for a cluster rocket, though, you may be using a much beefier igniter. Some of them pull quite a few amps, and most work best with 12 volts rather than 9. Some flight computers offer a *dual* *battery*option so you can connect a separate battery that delivers more voltage or amperage for firing motor igniters.

As I mentioned before, a few computers have radios that can broadcast a signal back to a ground station, delivering real-time updates on the rocket's status. These computers invariably have GPS units on board. You might hear the mechanical voice of the ground software at a launch, calmly announcing the altitude, or when the drogue and main events fire, or the speed, or the direction to look, or even the rocket's angle above the horizon. The ground software also shows the GPS location where the rocket landed. Pop the coordinates into your smartphone and you can walk directly to the landing site.

Choosing a 9-Volt Battery

Most igniters used for ejection charges fire well from a 9-volt battery. Assuming that is what you use, be sure to buy Duracell batteries. As you can see in Figure 7-4, 9-volt batteries are made with six internal 1.5-volt cells. Many battery brands are made with simple pressure connections to hold these interior cells together. Duracell batteries have soldered connections. While that may not be important for most applications, rockets get tossed around quite a bit, especially during ejection and landing. Those soldered connections might be the difference between maintaining power or losing it.

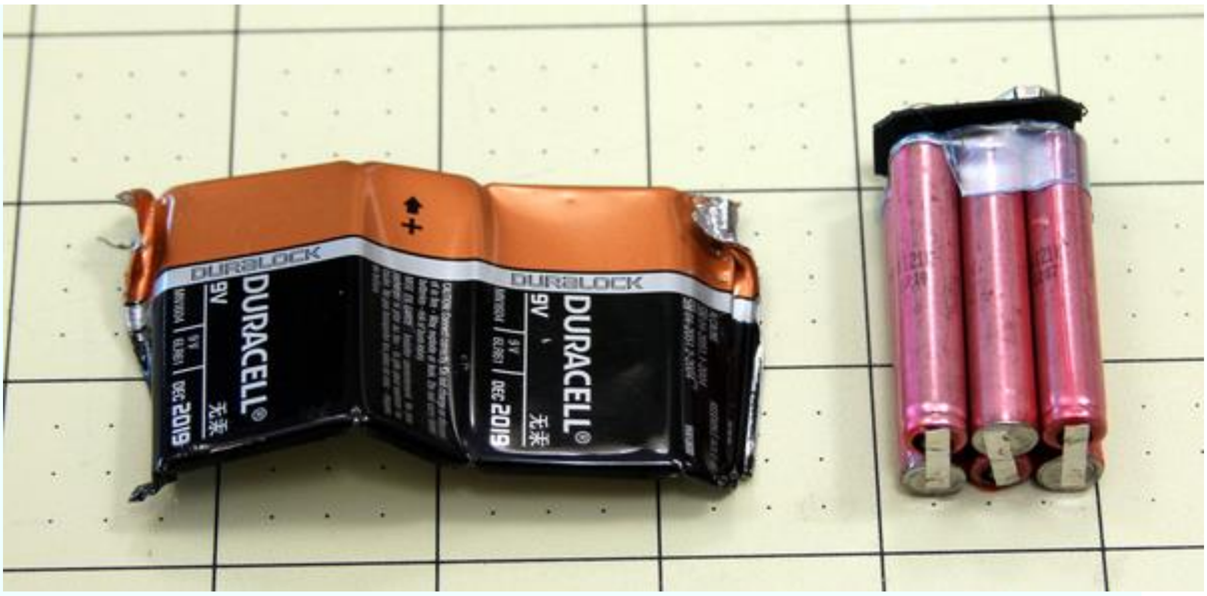


Figure 7-4. Disassemble a 9-volt battery before using it for rocketry. Duracell batteries have soldered connections.

I recommend using two flight computers instead of just one. If you do everything perfectly, and if all of the components in your recovery chain work perfectly, one flight computer is enough. But Captain Murphy was working with rocket sleds at Edwards Air Force Base in 1949 when he coined the now famous Murphy’s law, “Anything that can go wrong, will go wrong.” Murphy’s law could have been invented for rocket recovery systems.

Let’s assume for a moment that your recovery chain is about 95% effective. This is fairly close to estimates by NAR, and will do for our little thought experiment. That means you will have a recovery failure on about 1 flight in 20. Thinking back to the high-power rocket flights I’ve seen, I think this is pretty optimistic—I have helped pick up the wreckage of a once-beautiful rocket after the recovery system failed.

Now let’s assume you use two completely redundant recovery systems—two computers, two batteries, two charges, and two parachutes. With the assumption that failures are independent, you’ve reduced your failure rate from 1 in 20 to 1 in 400.

Of course, the real reduction isn’t quite that good. For one thing, we almost always use a single parachute, so a parachute failure will still cause the entire recovery system to fail. There are other dependencies, too. The point, though, is that you will dramatically decrease the chances of a recovery failure by using two computers. From bad igniters to wires that pulled loose, most of the recovery failures in high-power rocketry are related to the computer in some way, even when the computer itself is flawless. In many cases, the cause of the failure can be identified well enough to be sure that a second computer would have saved the flight.

This brings up the need for another feature you will see on many flight computers. They allow a small delay, usually no more than a second or so, between apogee and when the apogee event fires. This feature is designed specifically to let you use the computer as a backup computer. By spacing the primary and backup charges a second or so apart, you ensure that the two charges won’t fire at the same time, which might overpressure the rocket. If the first charge fires correctly, the second one fires harmlessly into the open air, after the drogue parachute deploys. This is why you will often see a puff of smoke about a second after the apogee parachute deploys.

Of course, you want to space the charges out for the main parachute deployment, too, but you don't need a special feature for that. Flight computers allow you to select the altitude for the main event. Use altitudes for the primary and backup computers that are 100 feet or more apart to give a little time between firing the main charges.

The launcher you've been using probably has some way of checking continuity for the motor igniter. You need some way to check the continuity for the igniters connected to your altimeter, too. Most altimeters have a tiny speaker that beeps out information before and after a flight. Before the flight, they might tell you the battery voltage, the altitude for the main event, or even the altitude for the last flight. The critical thing they will do, though, is give a series of beeps telling you if there are good connections for the drogue event and main event.

After the flight, some altimeters emit a loud sound to help you find the rocket. That doesn't help much until you get close, but it's a real asset if the rocket is in a cornfield or behind some other tall plant.

A feature I've already mentioned is the ability to download flight information. Not all computers have this feature. Those that do often support specific operating systems. Most support Windows, but a growing number of people use macOS or Linux. Some altimeters also have features that work with smartphones, often allowing you to check the status or reprogram the altimeter remotely, but they rarely support all smartphone models. Be sure the altimeter supports the operating system you use before shelling out the money to buy one.

With these features in mind, let's take a look at a pair of altimeters from Missile Works, the RRC3 and RRC2+ (shown in Figure 7-5). These altimeters use the same basic technology. They both also use the same microprocessor and barometer, and both have versions that work up to 40,000 feet and a second version that works up to 100,000 feet. They both have capacitors to prevent brownout if the battery disconnects for a moment—something we'll talk about later, when we look at how to install the computers. Both can fire a drogue event at apogee, and a main event at an altitude you select. Each has a speaker for continuity checks and to beep out the altitude after the flight.

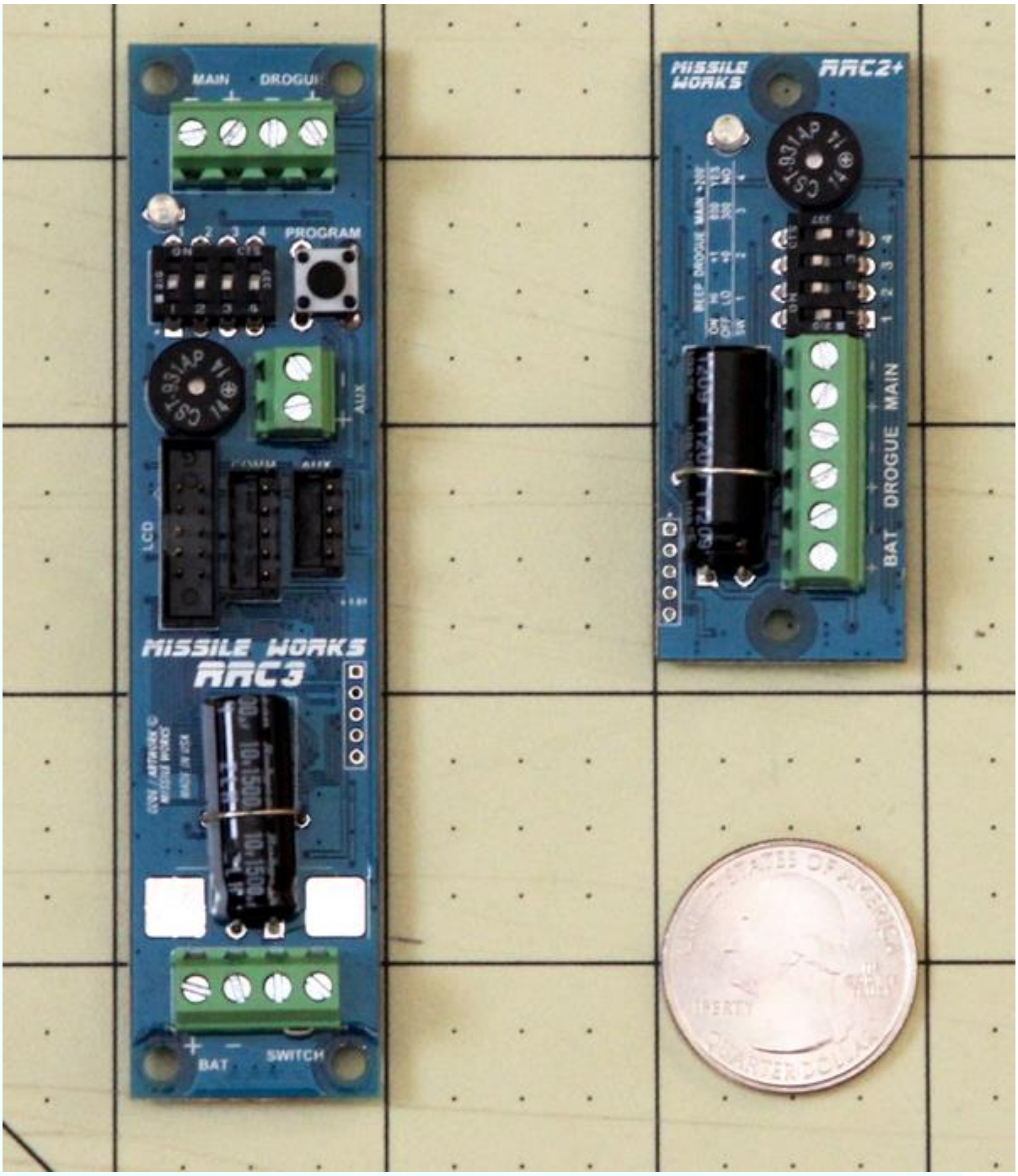
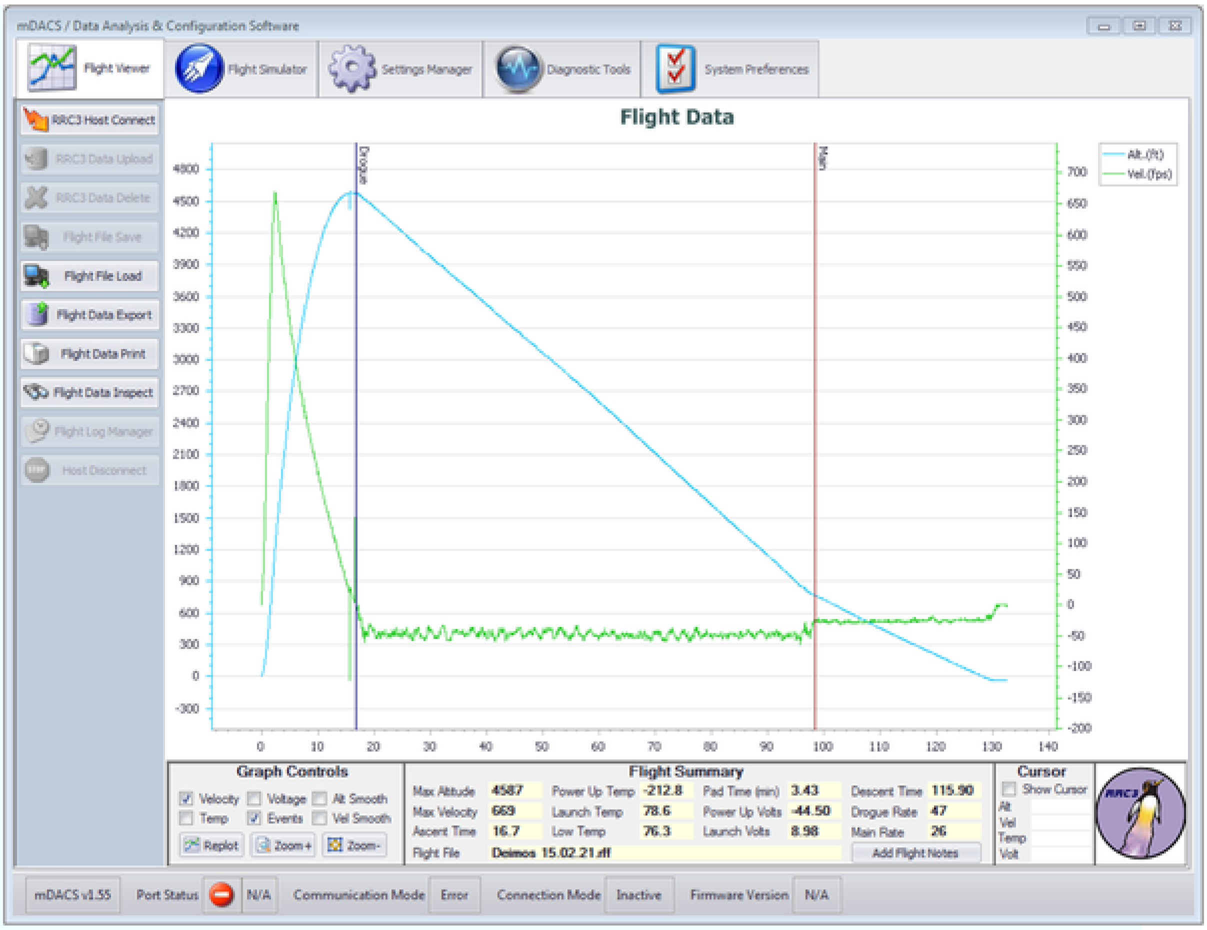


Figure 7-5. The Missile Works RRC2+ (right) and RRC3 (left) show the difference between a perfectly adequate budget altimeter and a high-end altimeter with three events and multiple external connection possibilities.

The big difference between the two is that the RRC3 also supports an additional programmable event. This can be used for staging, as discussed earlier, or even for firing backup drogue and main events. There are also three connectors on the altimeter. The one I use the most allows downloading flight data. Figure 7-6shows a download of the flight data from a flight of Deimos. The green line shows speed, which clearly changes when the main parachute is deployed at an altitude of 800 feet.



Max Altitude 4587
Max Velocity 669
Ascent Time 16.7
Flight File Deimos 15.02.21.rff
Power Up Temp -212.8
Launch Temp 78.6
Low Temp 76.3
Pad Time (min) 3.43
Power Up Volts -44.50
Launch Volts 8.98
Descent Time 115.90
Drogue Rate 47
Main Rate 26

mDACS v1.55
Port Status N/A
Communication Mode Error
Connection Mode Inactive
Firmware Version N/A

Figure 7-6. This screen capture from the mDACS software, a free program for accessing the RRC3, shows the altitude and speed for a flight of Deimos.

That same port used to download the data can also be used for other purposes, like controlling other onboard electronics. The other two ports are used for various external trigger events and connections to devices like LEDs that can be wired to the outside of the rocket for visual verification of the altimeter’s state.

Shear Pins

One of the things to consider as our rockets get bigger and fly faster is shear pins. Let’s take a moment to see why this might be important. As a thought experiment, consider a rocket that starts at sea level and flies to an altitude of 10,000 feet. That rocket will fly high enough that it will lose roughly 40% of the sea level air pressure, which is about 14.7 psi. That means the pressure inside the rocket is about 5.9 psi higher than outside the rocket. If it’s a 3”-diameter rocket like Deimos and Phobos, the nose cone or payload bay has an area of:

$$
\begin{aligned}
A &= \pi r^2 \\
A &= \pi 1.5^2 \\
A &= 7.1\ \mathrm{in}^2
\end{aligned}
$$

The force pushing on the payload bay is:

$$
\begin{aligned}
F &= PA \\
F &= 5.9 \times 7.1 \\
F &= 41.9\ \mathrm{lb}
\end{aligned}
$$

If you pull on the nose cone with over 40 pounds of force, do you think it will come off? If so, it could pop off on the way up, well before you want it to. While this is often called *drag separation*, it’s really *pressure separation*, and it can tear a rocket to shreds if it happens while the rocket is traveling at high speed.

One of the ways to prevent pressure separation is to drill vent holes in the sides of the rocket. You did this when building Deimos and/or Phobos in Chapter 6. This allows some of the air inside the rocket to escape as it climbs to altitude. Often, those vent holes are enough. If the rocket flies very high, very fast, or the diameter of the rocket is very large, though, vent holes may not suffice. That’s where shear pins come in.

Shear pins are usually plastic or nylon rods or screws that hold the rocket together, just like the screws we’ve used to fasten the nose cone to the payload section. The difference is that the shear pins are deliberately designed to be weak. The plan is that the ejection charge will be strong enough to break, or shear, the fasteners, allowing the payload bay to pop off and the parachute to deploy.

I am not aware of any accepted general wisdom on when to use shear pins and when they can be skipped. On my own rockets, I use shear pins when the rocket will go over 5,000 feet; when it will travel at Mach 0.8 or faster; when it has two parachute bays; or when it is larger than 3” in diameter, since a larger diameter means more pressure trying to separate the rocket. I use 1/16” styrene rods (shown in Figure 7-7), available at hobby stores that cater to model airplane enthusiasts, for 4.5”-diameter rockets and smaller, and 1/8” nylon bolts for larger rockets. With that in mind, I did not use shear pins on Deimos, since the 38 mm motors generally don’t pack enough punch to push the rocket all that high, but I do use shear pins on Phobos, whose 54 mm motor can propel it on 10,000-foot flights that exceed Mach 1.

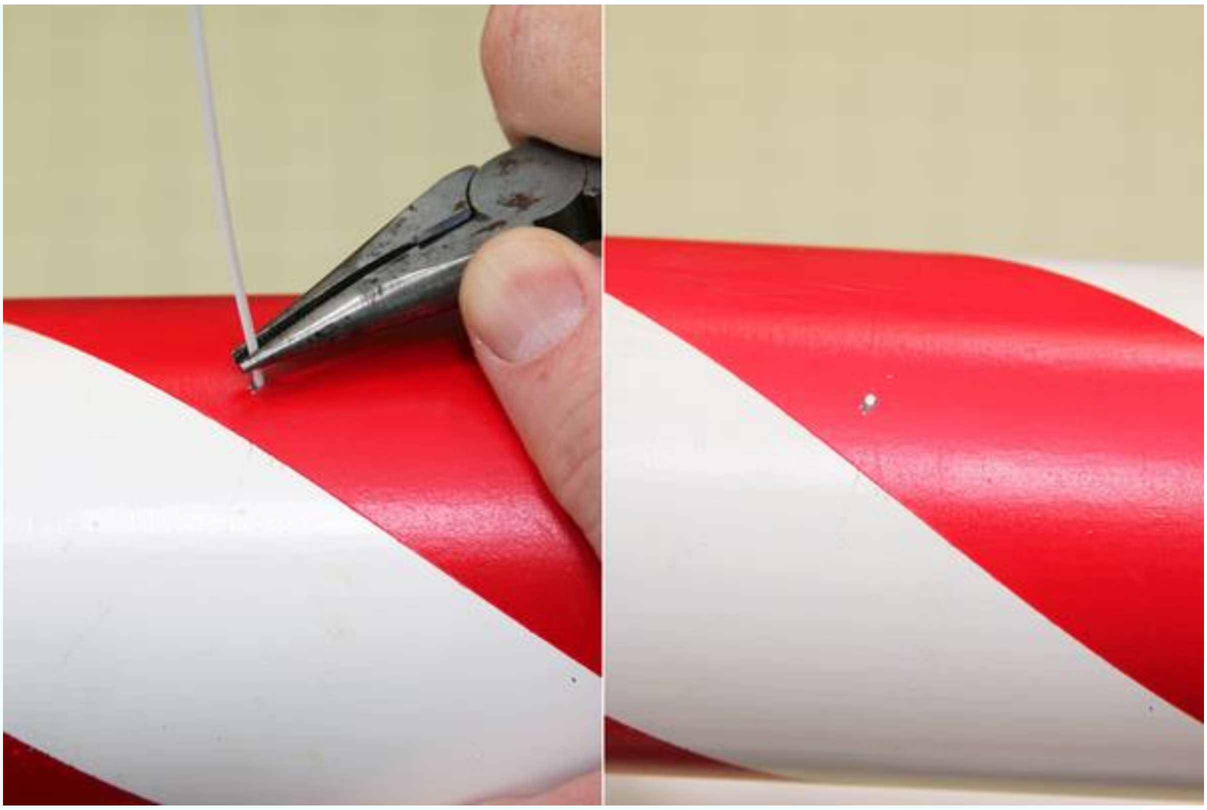


Figure 7-7. Installing 1/16” polystyrene shear pins in Phobos. Push the rod in far enough to stick through both the body tube and the tube coupler, and then give a sharp sideways jerk to snap it off flush with the surface of the body tube. Use pliers to apply enough force to get the shear pin through the holes.

Cable Cutters

There are two basic ways to achieve dual deployment. One requires two completely separate parachute bays, so it requires building the rocket specifically for dual deployment. We’ll look at that method in Chapter 8. The other works well with any standard rocket that has a payload bay or nose cone large enough to hold an altimeter. The idea is to pop out the main parachute at apogee, but to inhibit it somehow so it doesn’t open fully until the rocket reaches a much lower altitude. We’re going to look at cable cutters, which are the simplest way to do this.

The idea with a cable cutter is to eject the parachute at apogee, but keep it bound in a tight bundle using a cable tie or some other restraint. The parachute will flop around, acting as a streamer as the rocket falls. This, combined with the fact that the rocket has separated into two parts and is no longer a streamlined missile, keeps the rocket from picking up too much speed as it falls. If needed, a smaller drogue parachute can also be used. It slows the rocket down even more, but not as much as the main parachute will when it finally opens.

Once the rocket falls to the altitude where we want to deploy the main parachute, the cable tie holding the parachute closed is cut using a pyrotechnic cable cutter like the one shown in Figure 7-8.

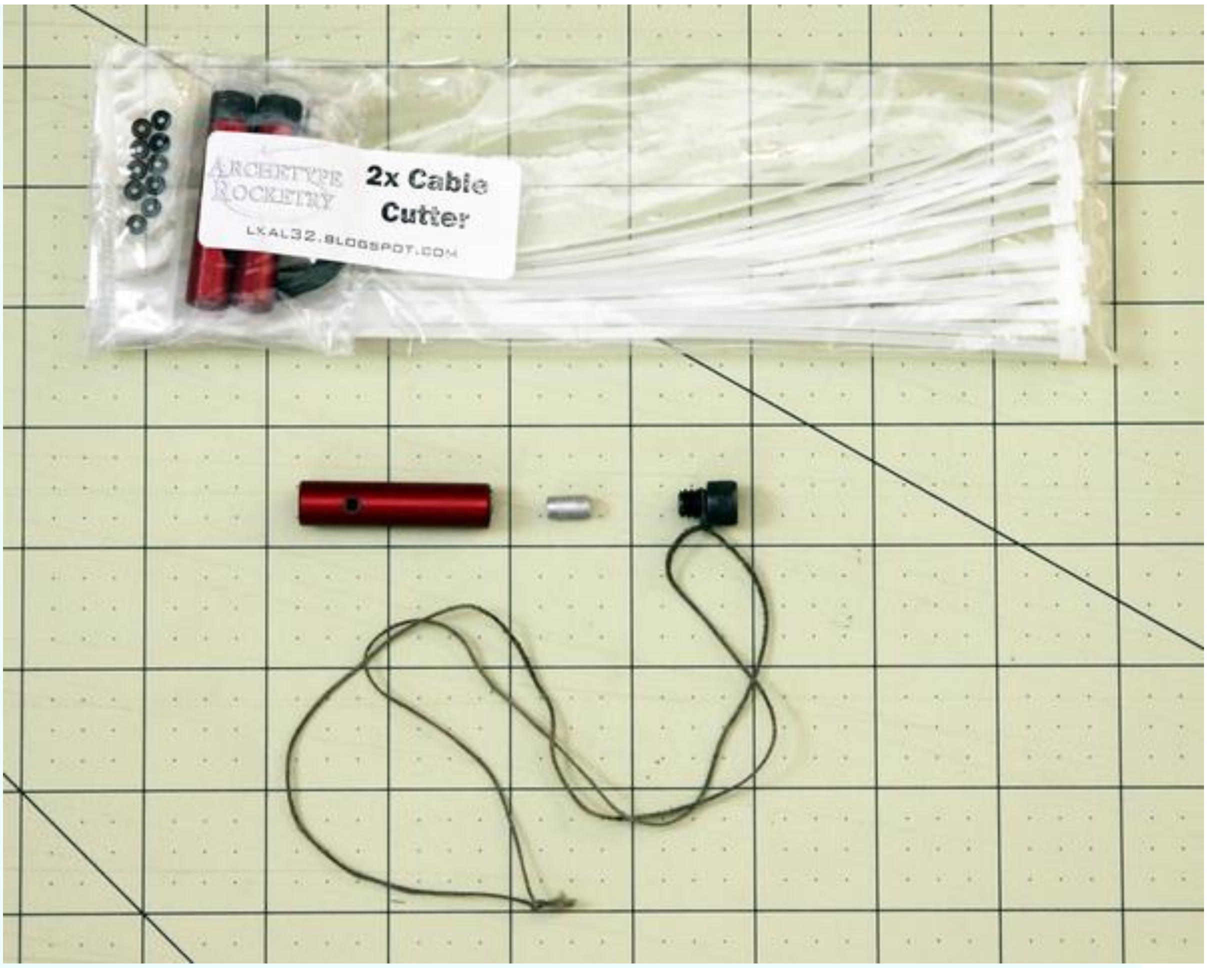


Figure 7-8. A pyrotechnic cable cutter holds a small black powder charge. This drives a piston that cuts a cable.

Originally developed by Archetype Rocketry, the cable cutter shown here is now sold by Prairie Twister Rocketry. The small aluminum plug is a piston that is pushed rather forcefully down the barrel of the cable cutter, severing the cable tie that fits through the hole in the side of the device. A standard igniter sets off the charge when the altimeter fires the main event. I generally use the Quest Q2G2 igniter for the job.

Building an Altimiter Sled

Most of the construction involves creating a sled to hold the electronics and mounting the sled in the rocket. The completed sled with electronics in place is shown in Figure 7-9.

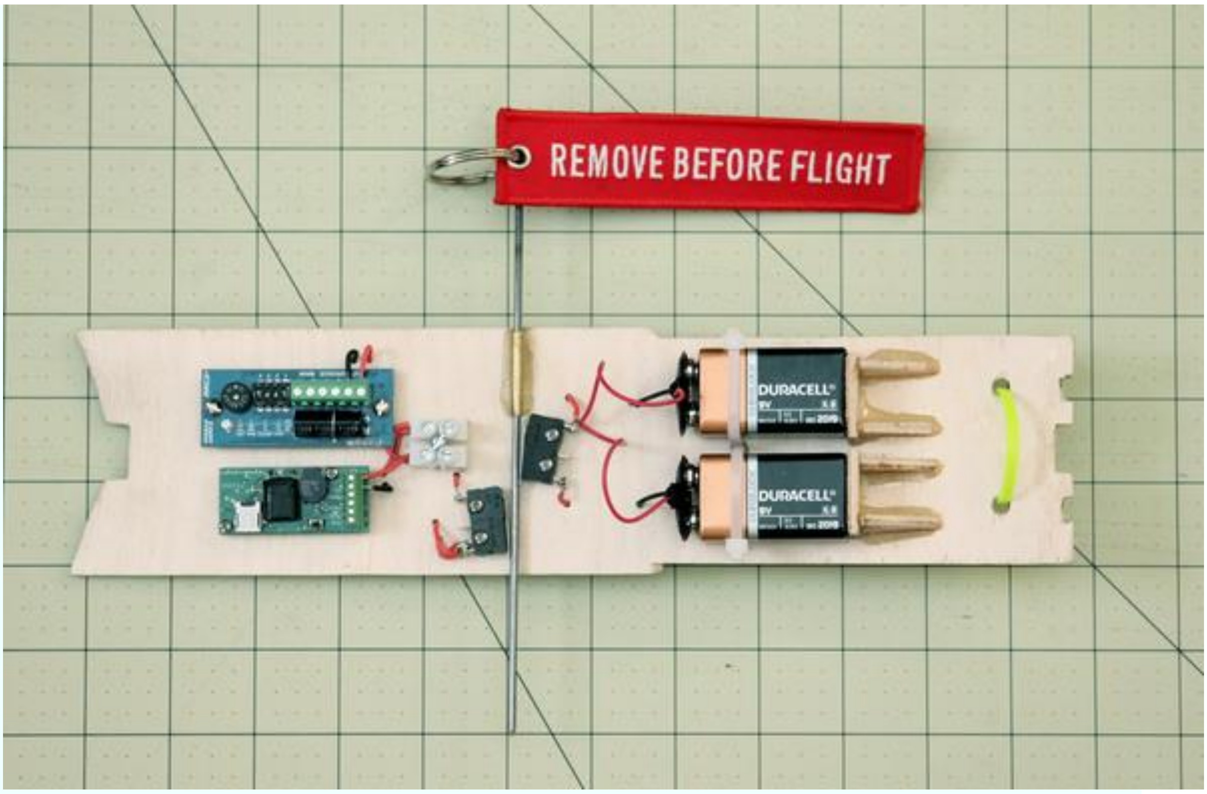


Figure 7-9. The completed altimeter sled for Deimos. A radio transmitter is attached to the back side; this is covered in Chapter 10.

It’s pretty easy to modify any rocket that has a payload bay to use this cable cutter. Let’s see how to do this with either Deimos or Phobos. Table 7-1 lists the parts used for the conversion you will see in the text, but keep in mind that there are lots of possible substitutions (the parts are also shown for reference in Figure 7-10). This chapter shows one good way to convert the rocket, but be on the lookout for ways to use tools and supplies that you have lying around that can be used in place of the ones shown here. Table 7-2 lists the specialized tools and supplies you need, beyond the basics like cutting tools, screwdrivers, and glue.

Part	Description
Altimeters (2)	You will need two altimeters capable of firing a main and drogu the RRC2+ and the Featherweight Raven.
Cable cutters (2)	The cable cutters shown come with cable ties.
Igniters	The text shows Quest Q2G2 igniters; electric matches work wel need four for the flight and one for each ejection charge test. Ge
Sled	We'll use a sled made from 1/8"-thick aircraft plywood to hold batteries (see Figure 7-9). Other materials, like plastic, also wor
9-volt batteries (2)	Get 9-volt Duracell batteries. The brand is important, for reason text.
Battery connectors (2)	9-volt battery connectors.
Switches (2)	Contact switches, such as the RadioShack model 275-016.
#2 screws (4)	1/2"-long #2 screws with nuts to mount the switches.
Terminal blocks	Get a terminal block strip, such as the RadioShack model 274-6 total of 10 terminals.
22-gauge hookup wire	It helps to have four different colors of stranded 22-gauge hook you can get by with fewer colors if you label the wires.
1/8" x 0.014" brass tube	Used to form a channel for the launch pin.
0.092" piano wire	Used to form the launch pin. This must slide into the brass tube
Flag	The flag shown in the following figures is a nice, official "remo flag, but a streamer or ribbon will work just fine, too.

Table 7-1. Parts list for retrofitting Deimos or Phobos with a cable cu

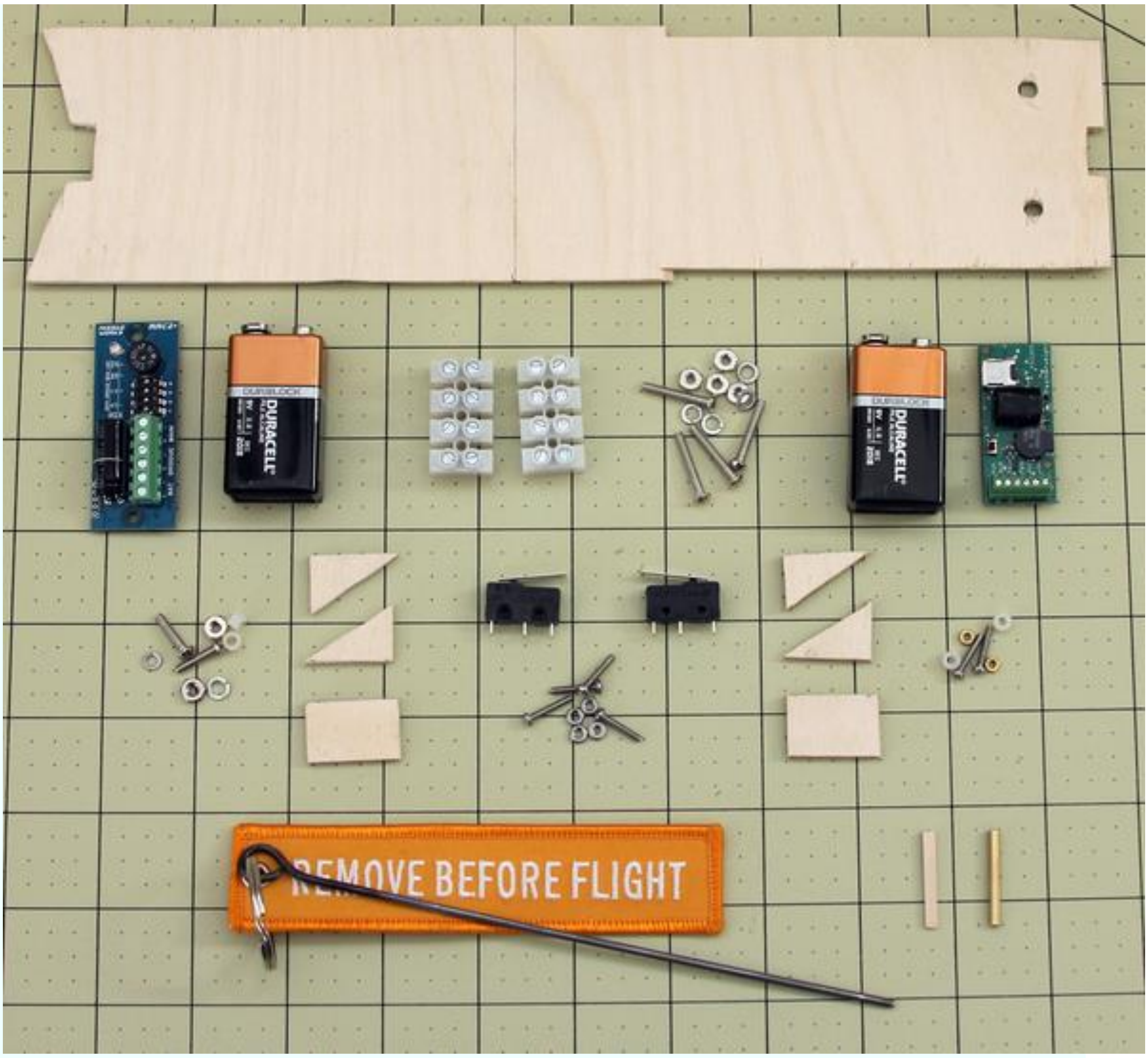


Figure 7-10. Visual parts list.

Part	**Description**
Soldering iron	You will be soldering wires together and tinning wires. You need so soldering iron, but it can be a pretty cheap one.
Rosin core solder	Any light-duty (i.e., thin) rosin core solder will work fine.
Bunsen burner	I used a Bunsen burner to heat the thick piano wire before bending i

Table 7-2. Specialized tools you will need

Finding Altimeter Vent Hole Sizes

Altimeters use a barometer to sense altitude, so we need to make sure the payload bay that holds the altimeters is properly vented to the outside air. While we need to let enough air into the payload chamber for the barometer to work, we don't want the holes to be too big. Holes that are too big add drag and, due to Bernoulli's principle, can also fool the altimeter while the rocket is traveling at high speed.

Bernoulli's Principle

Simply put, Bernoulli's principle says that when a gas like air has a high velocity, it also has a lower pressure. As air rushes past any holes we drill in the side of a rocket, this causes air inside the rocket to get sucked out to some degree, lowering the pressure inside the rocket. The same principle governs how airfoils on an airplane wing provide lift.

There are two good ways to find the ideal vent hole sizes for an altimeter. The first is to use a bit of simple algebra, and the second is to use a table. We'll look at both methods here. (There is a third method that is faster, but will only work for the rockets in this book: you can skip this whole section, since the construction directions tell you the hole size. That's OK—you can always come back and read this section later, when you really need it for your own rocket design.)

Over the years, a general guideline has emerged for altimeter vent hole sizes. The area of the holes should be 0.05 in^2 for every 100 in^3 of payload bay space. We typically use three or four holes spaced evenly around the body tube. If possible, the holes should be at least two body tube diameters from the base of the nose cone or any other protuberance that will interrupt the air flow, since that could cause shock waves that affect the flow of air across the openings.

Armed with this knowledge, you can figure out the hole sizes for Deimos's payload bay. The payload bay itself has an inside diameter of roughly 2 7/8" and an inside length of 14 1/2". We do need to account for the volume in the tube coupler that forms the shoulder, which is why the length is 14 1/2” rather than just the 12” length of the body tube.

The nose cone is hollow, so we need to add the volume of the nose cone, too. While we could figure it out fairly precisely using a mathematical description of the nose cone, or experimentally by filling the nose cone with water and measuring the resulting volume, it’s close enough for our purpose to treat the nose cone as a hollow cone.

Grabbing the equations for the volume of a cylinder and a cone from a handy reference source, we get the payload bay volume for Deimos:

$$V = \pi l r^2 + \pi r^2 \frac{h}{3}$$

The first term is the volume of a cylinder with a radius *r* and length *l*. The second term is the volume of a cone with a base radius of *r* and a height of *h*. Deimos’s nose cone is 13” long. Plugging in the values for Deimos, we get:

$$V = \pi \times 14.5 \times 1.4375^2 +$$

$$V = 122.26\,\mathrm{in}^3$$

This means we need vent holes with an area of:

$$A = 0.05 \frac{V}{100}$$

$$A = 0.05\frac{122.26}{100}$$

$$A = 0.0611\ \mathrm{in}^2$$

Since we are drilling three holes, each individual hole needs to have 1/3 of this area. Working back from the area of a circle, we can find the radius of the appropriate drill bit, which is:

$$A = \pi r^2$$

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{0.0204}{\pi}} = 0.0$$

This is a radius, not a diameter, so we need to double it to get the diameter of the drill bit. Multiplying that by 32 tells us the drill bit should be 5.16/32”, so a 5/32” bit will do nicely.

Now, I like doing little math exercises like this, and you should certainly be able to do it this way, too, since there are odd cases that pop up from time to time that force us to go back to basic principles. Still, this is a common calculation, and we can reduce it to a table. Table 7-3 shows the maximum length of a payload bay for a given body tube diameter and vent hole size when three vent holes are used (Table 7-4 shows the sizes when four holes are used). To use the table, start by finding the length of the payload bay. For Deimos, this is:

$$l = 14.5 + \frac{1}{3}13\ \mathrm{in}$$

Remember, we need to include the volume of the nose cone, so the length isn't just the length of the payload tube. The volume for a cone is the same as the volume for a cylinder that is 1/3 the height of the cone, so we can account for the nose cone by adding 1/3 of its length to the overall length of the payload bay.

The closest body tube size from Table 7-3 is 3.002", so we'll use that row. Scan across until you find a payload bay length that is 18.83" or longer. This time, we get a hole size of 3/16". This shows the weakness of using tables—since there wasn't an entry for the precise diameter of our body tube, the volume was a bit larger, and so is the port hole size. Still, while this is rocket science, we don't have to be exact in calculations like this one. Either of the hole sizes will work fine.

Body tube inside diameter (in)	**1/16"**	**3/32"**	**1/8"**	**5/32"**	**3/16"**	**7/32"**	**1/4"**
1.145	17.88	40.22	71.51	111.73	160.90	219.00	286.04
1.525	10.08	22.68	40.31	62.99	90.70	123.45	161.25
2.152	5.06	11.39	20.24	31.63	45.55	62.00	80.97
3.002	2.60	5.85	10.40	16.25	23.41	31.86	41.61
3.9	1.54	3.47	6.16	9.63	13.87	18.88	24.65
6.007	0.65	1.46	2.60	4.06	5.85	7.96	10.39
7.512	0.42	0.93	1.66	2.60	3.74	5.09	6.65
11.41	0.18	0.41	0.72	1.13	1.62	2.21	2.88

Table 7-3. Drill hole sizes for three altimeter vent holes

Body tube inside diameter (in)	**1/16"**	**3/32"**	**1/8"**	**5/32"**	**3/16"**	**7/32"**	**1/4"**
1.145	23.84	53.63	95.35	148.98	214.53	291.99	381.38

Body tube inside diameter (in)	**1/16”**	**3/32”**	**1/8”**	**5/32”**	**3/16”**	**7/32”**	**1/4”**
1.525	13.44	30.23	53.75	83.98	120.94	164.61	215.00
2.152	6.75	15.18	26.99	42.17	60.73	82.66	107.97
3.002	3.47	7.80	13.87	21.67	31.21	42.48	55.48
3.9	2.05	4.62	8.22	12.84	18.49	25.17	32.87
6.007	0.87	1.95	3.46	5.41	7.79	10.61	13.86
7.512	0.55	1.25	2.22	3.46	4.98	6.78	8.86
11.41	0.24	0.54	0.96	1.50	2.16	2.94	3.84

Table 7-4. Drill hole sizes for four altimeter vent holes

Modifying Deimos or Phobos for Dual Deploy

Start by drilling three altimeter vent holes in the payload bay. You can use the same cardboard fin guide that you used to position the fins to mark holes evenly around the circumference of the body tube. The holes should be 8” from the front end of the body tube. Each hole should be 5/32” in diameter.

All of the electronics are attached to a sled that will slide into the payload bay. You can use practically any stiff material for the sled. The parts list calls for 1/8”-thick aircraft plywood, but I have also used 1/8”-thick laser-cut plastic for altimeter sleds.

Glancing back at Figure 7-10, you’ll see that the sled has a rather irregular shape. The exact dimensions could vary a bit, depending on exactly how far you slid the tube coupler into the payload bay body tube, the specific nose cone you used, how far in the bulkhead plate that forms the base of the payload bay is relative to the bottom of the tube coupler, and even what screws you selected. Figure 7-11 shows the dimensions for the sled in my own build of Deimos, but be sure you measure your own rocket and modify the dimensions as needed.

For the most part, building a sled for Phobos is the same as building the sled for Deimos. There is one interesting difference, though. The fiberglass nose cone for Phobos doesn’t have a bottom, so the sled can slide into the nose cone. That’s actually rather nice, since it gives you more room to work with. Figure 7-12shows the sled for Phobos. This one was laser cut from 1/8”-thick plastic at my local makerspace, giving one more example of a material you can use for your sled. The computers used are the same ones you saw in Figure 7-9, but there is a lot more free space! The dimensions for the sled are in Figure 7-13. Once again, your exact dimensions may vary, so be sure to measure your rocket carefully rather than simply trusting these dimensions.

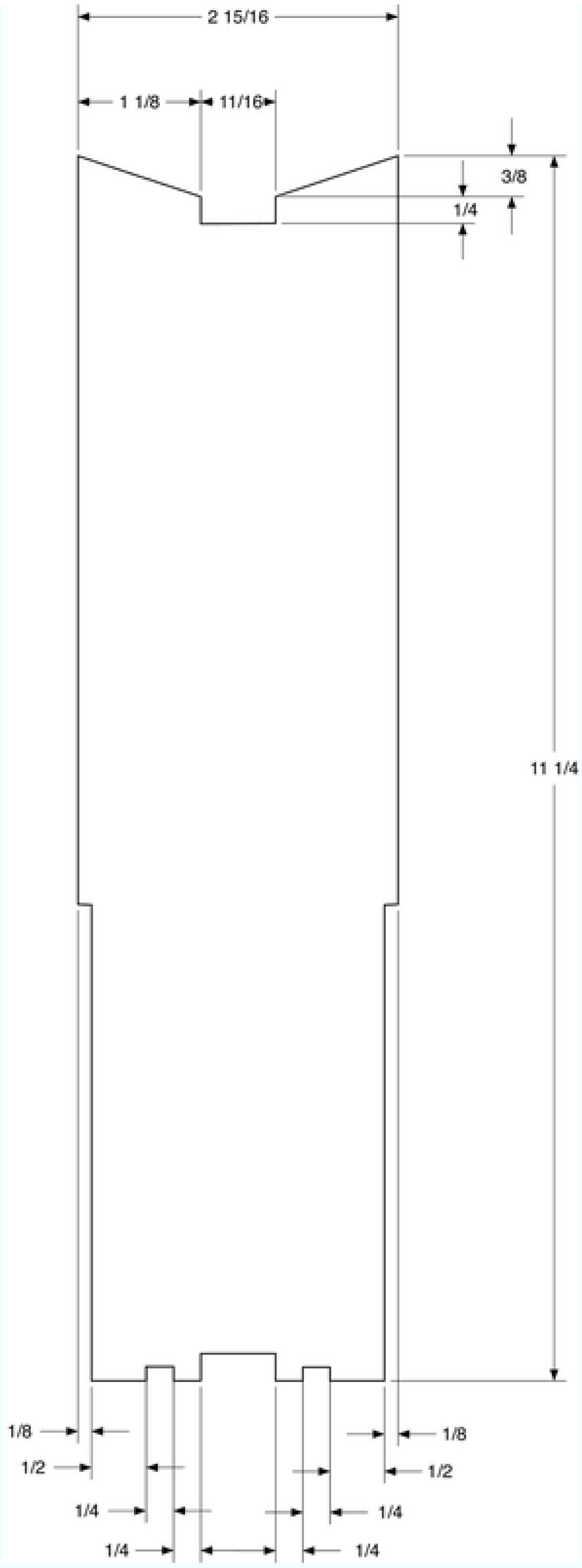

2 15/16
1 1/8
11/16
3/8
1/4
11 1/4
1/8
1/2
1/4
1/4
1/8
1/2
1/4
1/4

Figure 7-11. The sled for Deimos. Exact dimensions may vary.

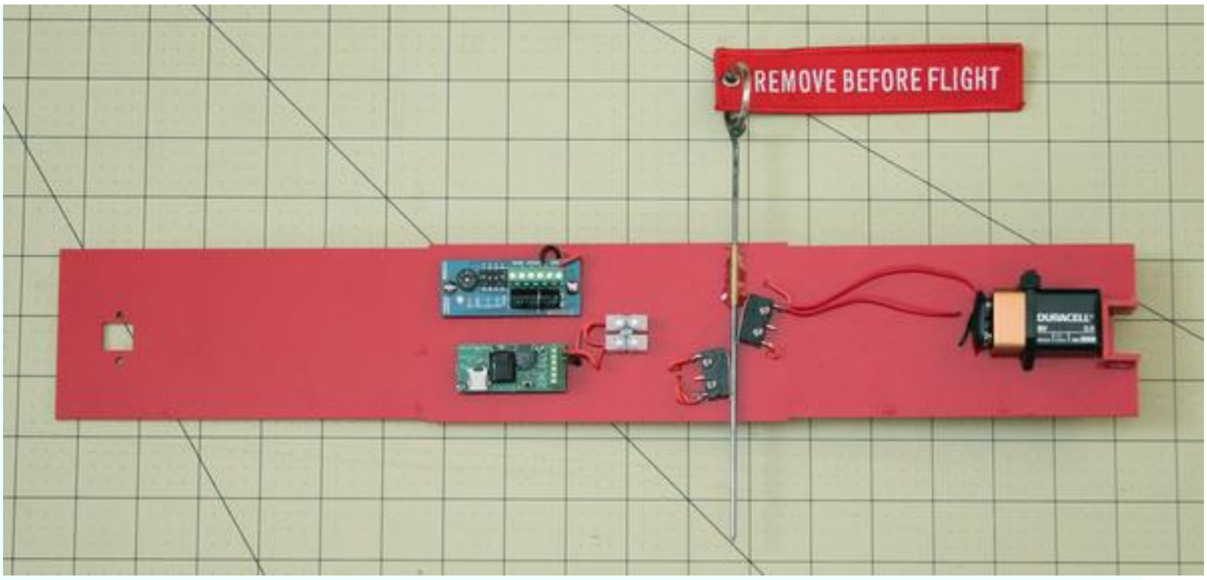


Figure 7-12. The electronics sled for Phobos. The hollow nose cone changes the size and shape substantially. The hole at the top fits a radio transmitter.

It’s worth noting that the sides of the sled are carefully cut so they fit against the edge of the payload bay tube and the tube couplers used as the shoulders of the payload bay and nose cone. It’s really important to make sure these fit correctly, especially at the top end. These tabs prevent the sled from sliding up into the nose cone as the payload bay bounces around during ejection and descent. That’s critical, since sliding up into the nose cone could pull loose some of the wires we’ll be installing a bit later, preventing the main parachute from deploying. This isn’t as big a problem for Deimos, since the nose cone on one end and the bulk plate on the other keep the sled contained, but the tabs must be present and in the correct spots on the Phobos sled to prevent the sled from sliding into the nose cone.

If you looked closely at the two sleds, you might have noticed that the battery mount is different. Figure 7-14 shows the two battery supports up close. For Deimos, I used a large, boxy radio transmitter that I wanted to mount at the bottom of the payload bay, so I moved the battery mounts up to make room for the cable tie that holds the radio transmitter in place. The triangular supports under the battery platforms provide additional mechanical support under high G loads. Since the radio transmitter is on the back side of the sled, both batteries are mounted on the front.

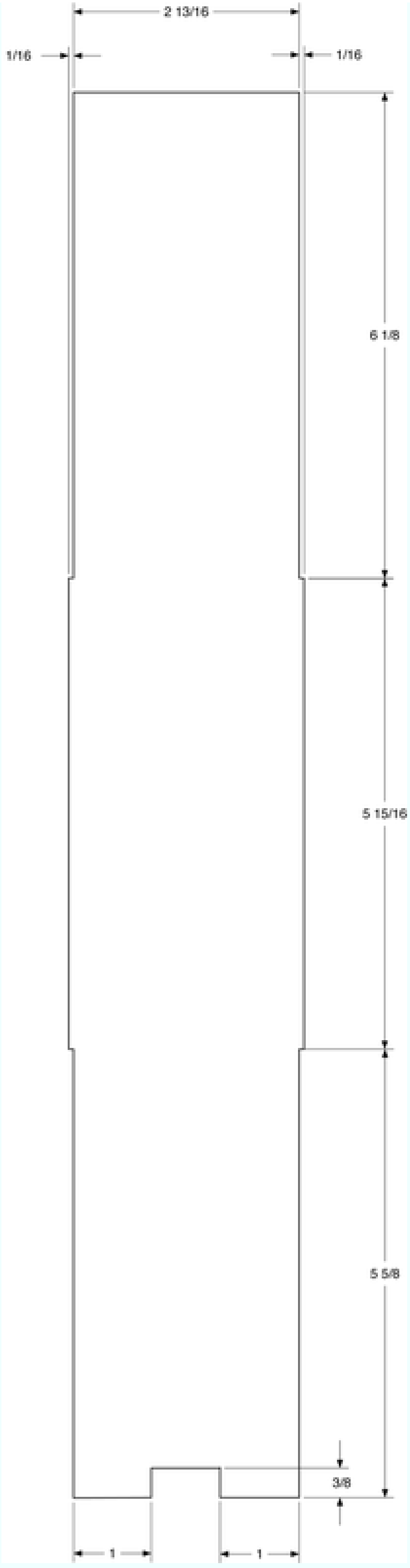

2 13/16
1/16
1/16
6 1/8
5 15/16
5 5/8
3/8
1
1

Figure 7-13. The sled for Phobos. Dimensions may vary, depending on the exact components used and the exact position of the bulk plate and tube couplers in the payload bay.

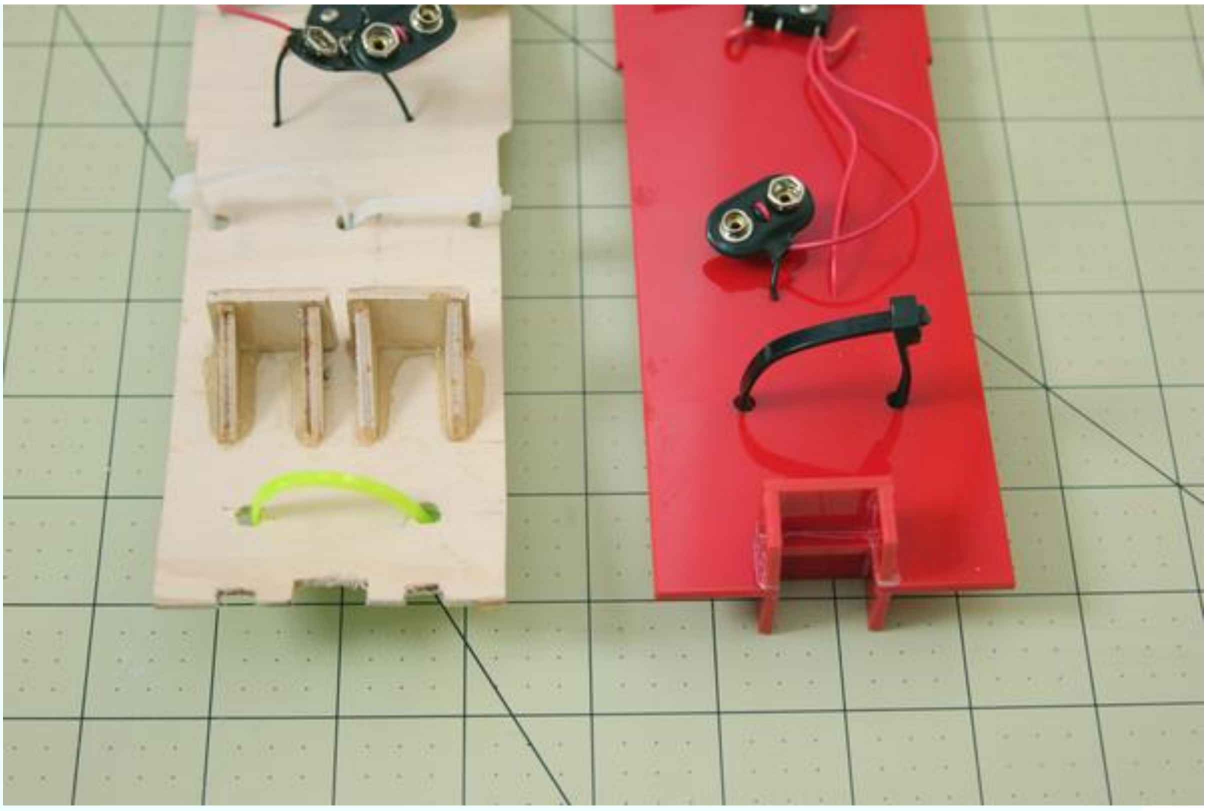


Figure 7-14. There are lots of good ways to mount the batteries, and lots of materials you can use for the sled.

I used a smaller radio transmitter for Phobos, and mounted it at the top of the sled. I mounted the batteries on opposite sides of the sled, using a single cable tie to hold both batteries. The supports extend to the bottom of the sled, where they sit directly on the bulk plate at the base of the payload bay.

I've used both designs in different rockets, and they both work just fine. Select the appropriate battery mount based on the components you need to mount on the sled, as I did. The one thing I would suggest is mounting the batteries near the bottom of the payload bay. That way, if one of them does manage to come loose during boost, it won't strip other components off of the sled as it falls to the bottom. There is no telling which way the batteries will fly off if they come loose when the ejection charges fire or during a rough landing. Sometimes, I add a second zip tie that wraps around the top and bottom of the batteries to reduce the chance of them slipping loose.

With the exception of the hollow nose cone and the different choice for mounting the batteries, the Phobos sled is built the same as the Deimos sled, so the rest of this section will only show the Deimos sled.

Slide the sled into the payload bay, making sure it slides all the way to the bottom, resting on the bulk plate. Twist the sled until the edge blocks one of the altimeter vent holes you drilled earlier. Mark the edge of the sled. This is the location for the pull pin we will use to turn the switches on or off. Remove the sled and draw a line across the sled at this point. The “remove before flight” pull pin will eventually cover this line. Refer back to Figure 7-9 for an overall view of the parts.

While you can make substitutions, the parts list calls for two RadioShack contact switches, part number 275-016. Position your switches so the pull pin will turn them off if it is in place, and so the switches will turn on when the pull pin is removed. Mark the positions of the screw holes and drill 3/32” holes for the four #2 screws that will hold the switches in place. You might want to temporarily mount the switches as you position the rest of the components.

Other Ideas for Switches

The text shows two contact switches and a pull pin for arming the altimeters. I like this method because there is a big, obvious flag on the side of the rocket, making it less likely the rocket will be launched without arming the altimeters. Other people use many other switch combinations, though. These include slide switches, magnetic switches, switches activated by a smartphone, and even simply twisting wires together. All of these options are fine, so long as you have a way to arm the altimeters on the pad, while the rocket is vertical, and you can easily disarm the rocket if needed.

Place your two altimeters on the sled and mark the positions for the screws that will hold them in place. The two altimeters you see in Figure 7-9 are a Featherweight Raven and a Missile Works RRC2+. The Raven uses #2 screws, so I drilled 3/32” holes, while the RRC2+ uses #4 screws, which need a 1/8” hole.

The Raven connects all of the positive wires together. You can handle this several ways. I choose to mount a terminal block on the sled to make it easy to connect the wires for both the drogue and main events.

You may or may not need to do something similar, depending on which altimeters you select. I drilled an additional 1/8” hole for the screw that holds the terminal block in place.

Forming the Arming Pin

The arming pin shown is made from 13-gauge wire, which is fairly stiff and brittle. That loop on the end for attaching the flag is hard to form with cold wire. The secret is to heat the wire until it is red hot using a Bunsen burner, and then bend the wire with needle-nose pliers. Quench the bent wire in a glass of cold water once the bend is complete.

Of course, this is a little overly engineered. You can also tape a piece of ribbon or a plastic streamer to the end of a straight rod.

Cable ties hold the batteries and radio in place. I drilled 3/16” holes so the cable ties could wrap through the sled. The position and size of the holes will vary, depending on the specific cable ties and battery configuration you use.

The pull switch is made from 0.092”-diameter piano wire, which is 13-gauge wire. The exact size is not important, as long as it is stiff enough to serve as a pin. Remember, the pin needs to slide into the bay and push the switch levers aside. You will also need a brass or aluminum tube to serve as a guide. The best way to find these materials is to go to a hobby store and grab some piano wire, then find a brass or aluminum tube (depending on what is available) that the wire will barely slip into. A 1/8” x 0.014” brass tube works well for 13-gauge wire. Cut a 1”-long piece of the brass tube and clean up the edges using sandpaper so the piano wire slides easily through the tube.

The flag can be easily found online and is sold by various vendors. Simply do a web search for “remove before flight flag” and you’ll find several sources where you can purchase it.

Choosing Wire

Pretty much any kind of wire will work for making connections between altimeters, batteries, switches, and igniters, but there are a few general rules to follow.

Twenty-two-gauge wire is a good choice for wire size. It’s small enough to fit into the terminal blocks on all of the altimeters I’ve tried, but large enough for the current that must be carried. This size is commonly known as hookup wire.

While aluminum wire will work, copper wire has a little less resistance. I prefer copper wire to aluminum, even though it costs a bit more.

Wire can be either stranded or solid. Stranded wire has multiple small wires bundled together in a common insulator, while solid wire is a single piece of wire in an insulator. Solid wire is easier to use, and works fine for connections like the ones on the sled. Stranded wire is a bit thicker, but it doesn’t break as easily from bending. Stranded wire is a better choice for the wiring we’ll do in a moment to hook the igniters to the altimeters because that wire gets bent a lot as the sled is connected and disconnected, then slid in and out of the payload tube.

You will also be making connections to four different igniters, and the only convenient way you will have to tell one from the other is the color of the wire.

Putting all of this together, plan on buying four different colors of stranded copper 22-gauge wire. If you want to make the job of wiring the sled a little easier, buy one or two colors of solid 22-gauge wire, too, but the stranded wire will work just fine.

Take a close look at your switches and the wire guide you just cut from the brass tube. You want the pull pin to hit the center of the switch levers, but if you mount it directly on the sled, the pull pin will be near one edge of the switch levers. I used a small piece of 1/16”-thick wood to lift the wire guide slightly off the bottom of the sled. Use quick-set epoxy to glue the wire guide and the sliver of wood used as an offset in place near the edge of the sled. Keep in mind that the body tube curves slightly—you don’t want the wire guide right at the edge of the sled. Set it back about 1/32” so it doesn’t hit the body tube as the sled slides into the payload bay.

Finally, glue your battery supports in place using quick-set epoxy. Your sled should look something like Figure 7-15, although the hole sizes and positions may vary, depending on the exact components you selected.

Mount the batteries, switches, and altimeters using 22-gauge hookup wire and two 9-volt battery connectors. The specific wiring diagram can vary a bit from one computer to the next, but the one shown in Figure 7-16is pretty typical. This diagram shows how the switches and batteries are wired to supply power to the two computers. I chose to set up the circuit so either switch can turn on both computers. This is a special bit of paranoia on my part. I don't want the altimeter to lose power when the rocket bounces around during the rather considerable vibrations created by liftoff, transonic flight, ejection charge deployment, parachutes snapping open, and so forth. While most altimeters, including the two I used, have a capacitor to prevent brownout if a switch opens for a moment, I don't want to take that chance. By wiring the circuit so either switch being closed will power both altimeters, and mounting them so any force likely to open one switch will close the other, there is almost no chance that a computer will lose power during flight.

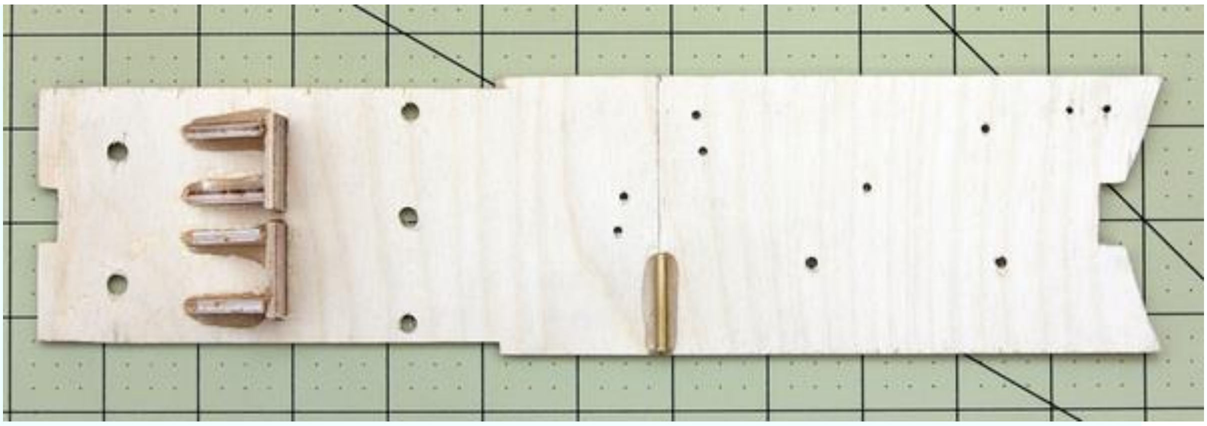


Figure 7-15. Drill appropriate holes for your components, and then mount the wire guide for the pull pin and the battery supports.

While the computers and batteries share the switches, notice that the wiring still maintains completely redundant electrical paths for the computers. The failure of one battery or one computer will have no effect at all on the other.

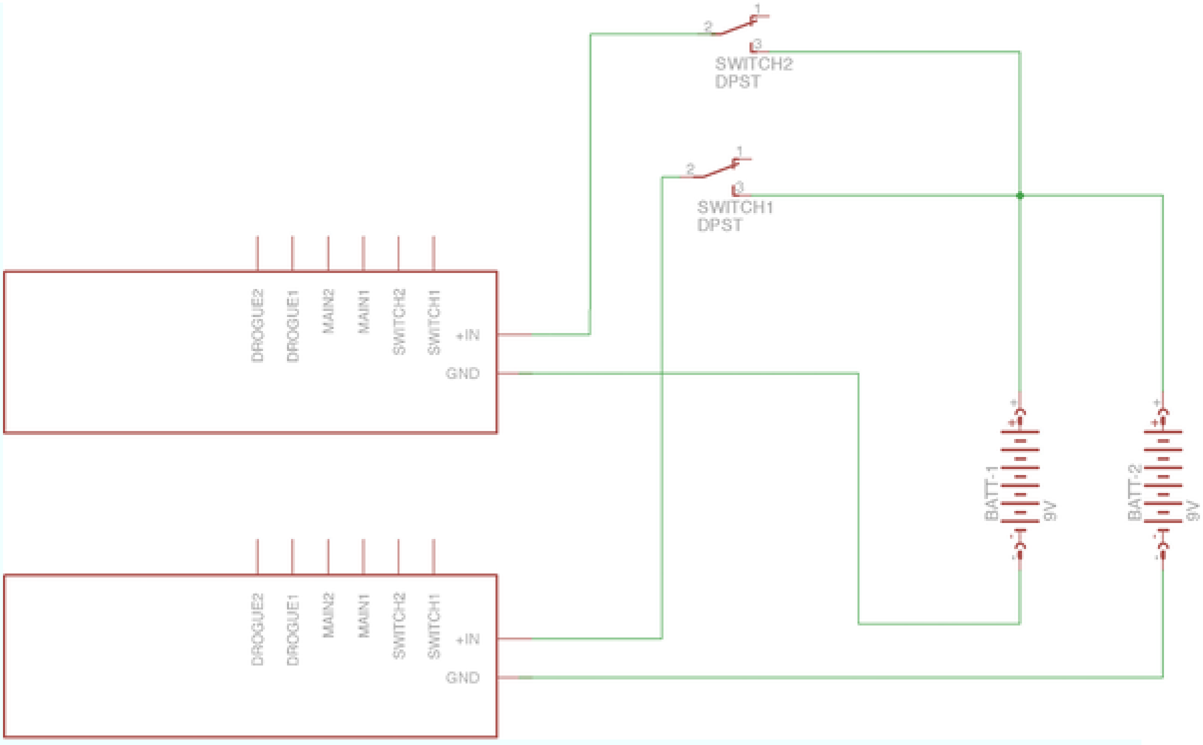


Figure 7-16. Wire the batteries, switches, and computers for maximum redundancy.

CAUTION

Be sure to wire the switches so they are closed when the pull pin is removed, and open when the pull pin is inserted. You want to cut power to the altimeters when the pull pin is in place, and provide power when it is removed.

The completed sled should look something like Figure 7-9, although there will be some differences if you used different computers or tracking equipment.

Cut two four-position terminal blocks from a terminal block strip such as RadioShack part 274-680. Attach these to the bottom of the bulk plate on the payload bay using epoxy glue or screws. Drill a hole in the base of the payload bay large enough to accommodate eight strands of hookup wire.

Cut eight 24”-long strands of 22-gauge stranded hookup wire. You need four different colors, with two strands of each color. While 24” might seem like it is way too long, you’ll thank me later when you are connecting the wires to the computers. It’s pretty easy to fold the excess wire into the payload tube. After a few flights, you can also cut the wire if you think it is too long, but it is a lot more difficult to change the wire if it ends up being too short.

Trim about 1/4” of insulation from the end of each wire and tin the ends. Tinning means you will twist the strands into a solid bundle and apply a small amount of solder to hold the strands together. This makes it a lot less likely a strand of wire will slip loose and cause a short.

Feed the eight wires through the hole in the bulkhead. Attach the wires to one side of the terminal blocks in pairs, so the wires of the same color are next to each other. Pull the wires through until they are taut in the hole. Fill the hole with fast-curing epoxy glue. You need to make sure you seal the hole completely. You’re not trying to hold the wire in place, you are trying to make an airtight seal. You don’t want any ejection charge gases to leak into the payload bay, since that can damage the altimeter.

When you are finished, your payload bay bulkhead will look like Figure 7-17. Note that the terminal blocks are marked D for drogue and M for main.

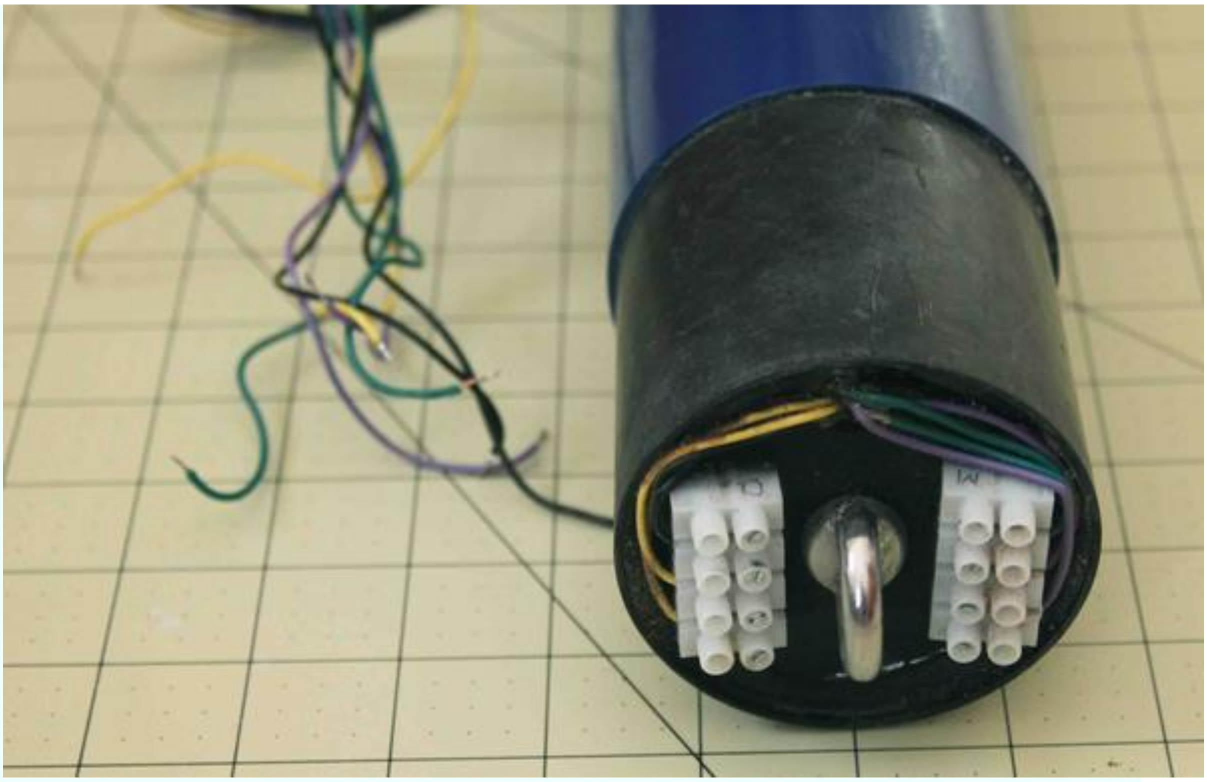


Figure 7-17. Wiring for the payload bay includes eight wires in four colors to connect the terminal blocks.

Picking the Size for Recovery Charges

Almost all high-power rockets use a black powder charge to eject the parachute. You need to figure out the correct amount of black powder to use for the charge. Too much, and the rocket can literally explode. Too little, and the pieces don’t separate, or they separate but the parachute does not come out. I’ve seen both happen several times.

There are two stages to picking a proper amount of black powder for a recovery charge. The first is to do a little math to find the theoretical charge size. The second is to give it a try with a ground test. Let’s start with the theory.

Predicting the Recovery Charge Size

There are several simple general rules for predicting the correct recovery charge size. All of them work to one degree or another, but all of them also fail with some rockets. We’ll start by working through the theory, which will point out why the simplistic methods fail. This section closes with a table that should get you close.

If you are just building the rocket as designed, and don’t want to deal with all of this just yet, I’ll save you some trouble. Use 1.2 cc of FFFFG black powder for Deimos, which is a bit lighter than Phobos, and 1.5 cc of FFFFG black powder for Phobos. Different construction, slightly different parts, or different fits for the parts can still cause differences in the amount of black powder you should use, though, so don’t skip the next section on performing a ground test.

If you don’t care about the theory, skip to the end of this section, where you will find a simple table that will get you pretty close. The table is almost as good as actually understanding what you are doing. Combined with a ground test, it will do just fine.

Most ejection charges for high-power model rockets are made using FFFFG black powder, often written 4FG. It’s hard to find at a local gun shop, so let’s start off by looking at why it is important to get

FFFFG black powder, as well as briefly discussing the dirty little secret that FFFG (3FG) black powder will work most of the time, too.

Black Powder Grades

The FFFFG designation you see here is only one of several ways to label black powder. It’s called *sporting grade*, and it’s the labeling most common in sporting goods stores and gun shops. You may also find blasting grade black powder, which ends with an A instead of a G. FFFFG is equivalent to 7FA, or FFFFFFFA. With four Fs, it’s tempting to switch to the 4FG notation, but I’ve seen FFFFG on the cans, so that’s what I used here. With seven Fs, it’s pretty much essential to use 7FA.

If all else fails, you can also look for the grain size. FFFFG black powder has a grain size of 0.15–0.42 mm.

Commercial grade black powder, also called gunpowder, isn’t really a powder at all. It’s a granulized solid made up of fairly uniform small pellets called grains. More Fs in the grade mean smaller grains in the black powder, so FFFFG has smaller grains than FFFG.

Larger grains have a smaller surface area compared to their volume than a small grain. Since the black powder burns inward from the surface, a larger grain will burn slower than a small one. Larger grains are used for devices that need some time to push a projectile out of a large barrel. The grade below FG, for example, is simply called cannon grade. That’s right. It’s for your cannon. It takes some time to push a cannonball along a barrel.

And that’s why we want FFFFG black powder—it burns faster, filling the body tube with pressurized gas quickly, before it can leak out of the vent holes we drill in the rocket to prevent changing air pressure from blowing it apart early. The slower the black powder burns, the more likely it is to simply leak out of the vent holes, back through the motor, or through cracks between the body tube and nose cone shoulder. That said, FFFG black powder will work in a pinch, especially on smaller rockets that don’t have vent holes.

You need to make sure you have good protection for your parachute, since either grain size will burn as it disperses through the chamber. FFFG will burn longer, so parachute protection is a little harder, but I’ve used FFFG many times. Still, you might as well use FFFFG black powder. It’s probably not available at your local sporting goods store, so plan ahead. One option is to order some, and pay the same hazardous materials shipping charge that you do for rocket motor reloads. A better option is to ask folks at your local rocket club. It’s very likely someone will be willing to sell you all or part of a can of black powder. It’s generally sold in one-pound cans. A pound of black powder will last a long time on rockets the size of Deimos and Phobos.

When your ejection charge lights, it rapidly converts a small volume of solid black powder into a large volume of hot gas. That’s what pushes the parts of the rocket apart. The ideal gas law states:

$$PV = nRT$$

P is the pressure. That’s actually what we want to know, because we’ll be able to use it to figure out how much force the charge will apply to the parts it is pushing apart. We’ll pick our other units so the pressure is in the familiar unit of pounds per square inch, or psi.

V is the volume. This is the volume we’re filling with gas as the black powder expands. We’ll use cubic inches, which you already know how to calculate from finding altimeter port hole sizes.

n is the mass of the black powder. Since we’re using imperial units everywhere else, this needs to be in pounds, but black powder is generally measured in grams, even in the United States. There are 453.59 g/lb.

R is a constant that makes all of this work. It varies depending on the gas you are using. For black powder, it’s 266 inches.

T is the temperature. While we are working in imperial units, the units for temperature may seem a bit odd. That’s because we’re measuring temperature in degrees above absolute zero, so we use degrees Rankine, abbreviated °R. You can convert from degrees Fahrenheit to degrees Rankine by adding 459.67. The temperature we’re after is the temperature of the gunpowder gas and particulates right after it burns, which is 3307 °R.

Putting all of this together, along with the conversion from pounds of black powder to grams of black powder, we find that the pressure exerted by a specific mass of black powder, *m*, measured in grams, when it is burned in a volume *V*, measured in cubic inches, is:

$$PV = \frac{m}{453.59} 266 \times 3307$$

$$P = 1939.33 \frac{m}{V} \frac{\text{lb}}{\text{in}^2}$$

This pressure pushes against the various parts of the rocket. The particular part we are concerned with is the base of the shoulder of the payload bay. That’s what is pushed out of the body tube to eject the parachute. The force applied to push the payload tube out of the body tube is:

$$F = PA$$

where *P* is the pressure, *A* is the area of the base of the payload bay, and *F* is the resulting force in pounds.

Several references suggest that you want the ejection charge to supply a pressure of 15 psi. Deimos and Phobos both have an inside body tube diameter of about 3”, so the force this will generate to separate the parts of the rocket is:

$$F = PA$$

$$F = 15 \times \pi \times 1.5^2$$

$$F = 106\,\text{lb}$$

That might seem like a lot of force, but remember that you're trying to pop the components apart quickly enough to pull the shock cord and parachute out of a tube, since the charges often sit on top of the parachute rather than under it, as they do with a motor based ejection charge. This really is about right for a 3" rocket. Some rockets can be quite a bit larger, though. For example, for a 10"-diameter rocket at 15 psi, the force works out to 1,178 lb! That's probably a bit too much force, and could easily blow the rocket apart. And that's why it's not a good idea to use a simple formula based solely on the volume of the parachute bay for calculating the amount of black powder to use. A good first approximation is to use 15 psi for body tubes from 2" through 5 1/2" diameter, then reduce the pressure to keep the total force around 350 lb. That may not be quite enough for some rockets, but ground testing will show whether you need more black powder, and you can increase it slowly until the charge is adequate.

Just as we need to lower the pressure for really large-diameter body tubes, we need to raise it a bit for smaller body tubes. For example, Estes low-power motors use about 1/4 g for the ejection charge. For a 1"-diameter body tube with a 9"-long parachute bay, that works out to an internal pressure of about 69 psi. The separation force is about 54 lb, considerably lower than for a larger rocket, but the pressure needed to get this force is higher.

Let's put this to use for Deimos. Remembering to subtract off the space occupied by the payload bay shoulder, the parachute bay for Deimos is 3" in diameter and 21 1/2" long. The parachute and shock cord take up some space, but not as much as you might think. The parachute is mostly air, after all. With most motors, there is also a little extra volume in the motor mount tube. We don't need to be quite that accurate, so we simply ignore those small adjustments to volume. This gives a volume of:

$$V = \pi l r^2$$

$$V = \pi 21.5 \times 1.5^2$$

$$V = 151.97\ \text{in}^3$$

The area the pressure pushes on to move the payload bay out of the main body tube is:

$$A = \pi r^2$$
$$A = \pi 1.5^2$$
$$A = 7.07\ \text{in}^2$$

Rearranging the pressure equation, the amount of black powder needed to achieve a pressure of 15 psi is:

$$m = \frac{P \times V}{1939.33}\ \text{g}$$
$$m = \frac{15 \times 151.97}{1939.33}\ \text{g}$$
$$m = 1.17\ \text{g}$$

This will generate a separation force of:

$$F = PA$$
$$F = 15 \times 7.07\ \text{psi}$$

$$F = 106\ \text{psi}$$

As I mentioned at the start of this section, there are oddball cases where it is important to understand the theory. It’s a bit tedious to do these calculations for every rocket, though. Table 7-5 lists ejection charge masses for common high-power rocketry body tube sizes. The inside diameter is along the left, and the internal length of the parachute bay is across the top. The table uses 15 psi for body tubes smaller than 5.5” in diameter, and 350 lb of separation force for larger tube sizes. That’s why the values for 6” and 7.51” body tubes are the same—for larger tube sizes, we always start with a charge that generates 350 lb of force.

Using the table, we get 1.15 g of black powder for Deimos. There is a bit of rounding error, but this gets us pretty close.

	6	9	12	15	18
1.53	0.09	0.13	0.17	0.21	0.26
2.15	0.17	0.25	0.34	0.42	0.51
2.56	0.24	0.36	0.48	0.60	0.72
3.00	0.33	0.49	0.66	0.82	0.98
3.90	0.55	0.83	1.11	1.39	1.66
5.38	1.05	1.58	2.11	2.64	3.16
6.00	1.08	1.62	2.17	2.71	3.25
7.51	1.08	1.62	2.17	2.71	3.25

Table 7-5. Black powder ejection charge size—the rows are body tube diameters, wh
parachute bay internal lengths; the values in the table are the weights of black p

Testing Recovery Charges

Theory is fine, but you don’t want to find out that you made a mistake as you watch your rocket scream in from 5,000 feet because the ejection charge wasn’t quite big enough. You should always test the ejection charge before use. Let’s see how that is done for Deimos.

From the previous section, we expect that the ejection charge will be about 1.17 g, which we will round to 1.2 g. Assemble the rocket just as if you were going to fly it. Put a motor case in the motor mount, blocking the forward end with cardboard and tape if necessary. Install the parachute you will use, just like you did when flying Callisto.

You don’t need to install the sled and computers for this test, although you certainly can. Measure 1.2 g of FFFFG black powder and place it in an enclosed container. There are a lot of different things you can use for the container. Some fliers build small aluminum charge canisters into the bottom of the bulkhead. I’ve done that, and it works fine.

Measuring Black Powder

There are lots of ways to measure small amounts of black powder. It’s often more convenient to measure a volume than a weight. It turns out that one gram of black powder is pretty close to one cubic centimeter of black powder, so you can measure the charges in cc rather than grams.

Gun stores and some rocket companies sell scales or devices that measure a small amount of material based on volume. Both work well. I saved some of the small medical sample tubes AeroTech ships its ejection charges in. These have volumes marked on the side, and work great for measuring black powder (Figure 7-18).

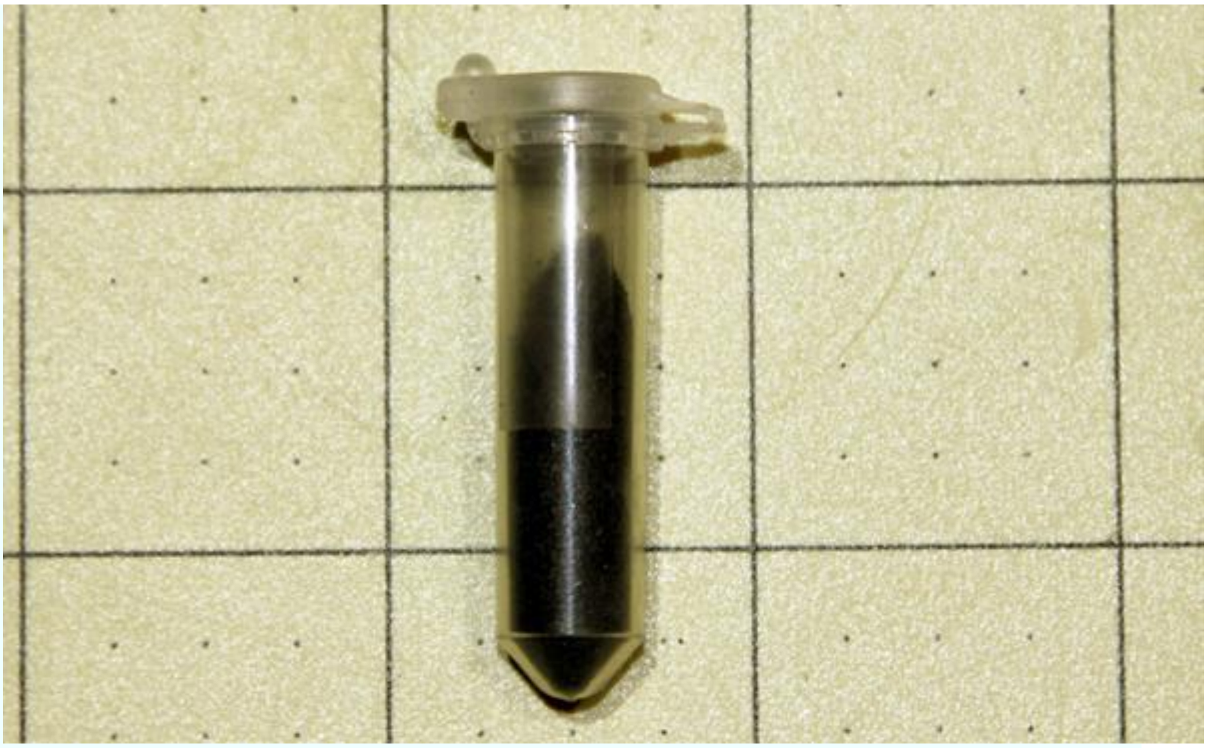


Figure 7-18. Save some vials from AeroTech ejection charges to measure black powder.

Most people I know use a small disposable container to hold the black powder, and tape this to the bottom of the bulkhead. The assembly of a black powder charge, igniter, and container is called a *squib* (Figure 7-19). For the container, one person I know swears by the corner of a Doritos bag. Another uses a short length of surgical tubing. I tend to use a finger cut from a disposable latex glove. Whatever you decide to use, dump the black powder into your container and insert an igniter. Secure the opening with tape. Write the size of the charge on the squib using a felt-tip marker. There will be days when you don’t end up flying, and don’t install the squib. It’s tough to tell by looking if a squib has 1.2 g or 1.5 g of black powder, but the difference is critical.

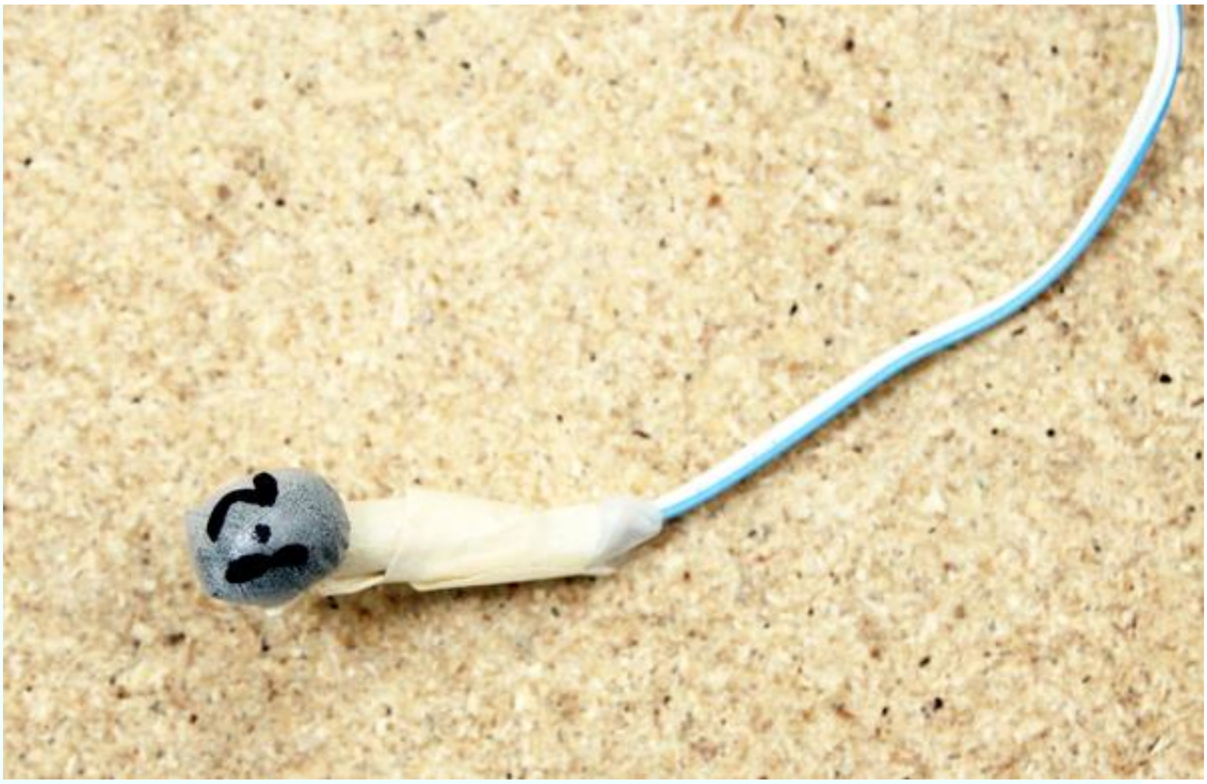


Figure 7-19. Use the finger from a disposable glove, the corner from a Doritos bag, or whatever your personal favorite happens to be to make two 1.2 g squibs.

Tape this to the bottom of the bulkhead. Connect the charge to one pair of wires on a terminal block. Although Figure 7-20 does not show this, I always add a layer of tape across the entire bulkhead, especially the terminal blocks. This protects the wiring and terminal blocks from the black powder charge.

Run the two wires for this terminal block out of one of the altimeter vent holes. Connect some handy ignition system, such as a low-power launch controller or a long piece of wire, to these wires. Whatever you use, be sure you are 15 feet or more away from the rocket when you fire the charge.

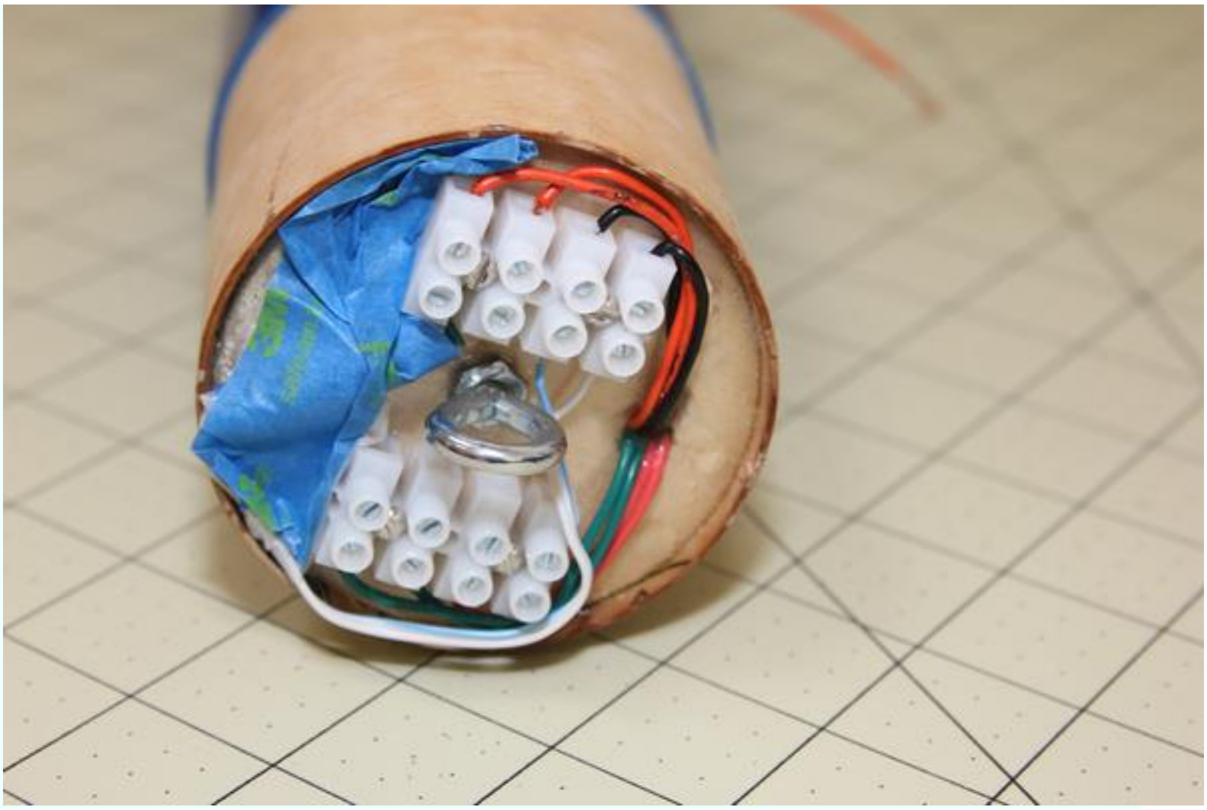


Figure 7-20. Tape the squib to the bottom of the bulkhead and connect it to a pair of wires using the terminal block.

Finish the assembly of the rocket, adding shear pins if you intend to use them when you fly. Other than not including the motor reload and computer sled, the rocket should be assembled exactly the way you will fly it. In particular, the parachute and shock cord should be packed exactly the way you expect to pack them for flight.

WARNING

The nose cone and body tube can separate with a lot of force, especially if you calculate the charge incorrectly. Make sure there is plenty of space in front of and behind the rocket. Make sure nothing delicate or important (such as yourself or another person or animal) is in the path of the nose cone or rocket when the charge is set off.

Stand back at least 15 feet, give a short countdown, and fire the charge. Did the parachute pop all the way out of the tube? If not, increase the amount of black powder by, say, 25% and try again. Figure 7-21 shows a successful test of Deimos.

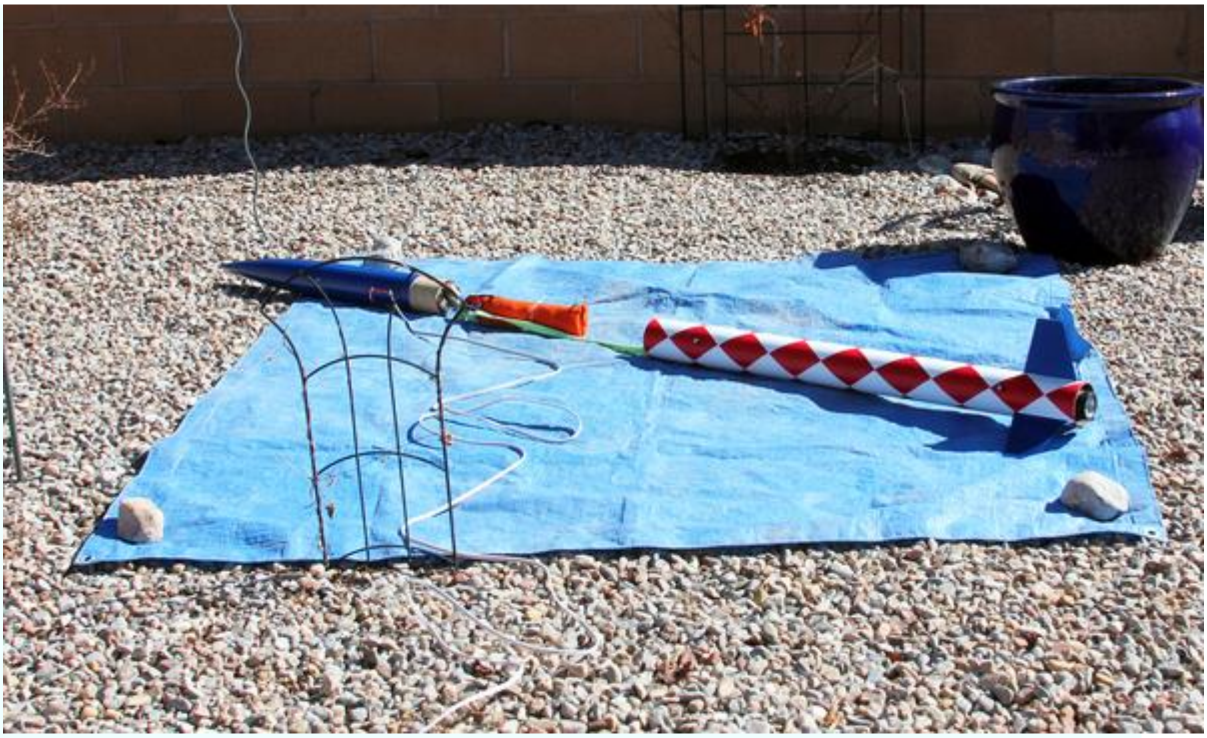


Figure 7-21. Deimos after a successful ejection charge test. The parachute is still bound in the flame blanket, wrapped in a zip tie, just as it would be for flight. The cable cutter would cut the zip tie later in the flight.

For my tests, I found that 1.2 g of black powder worked quite well for Deimos. Phobos didn't quite pop apart energetically enough to suit me, so I increased the amount of black powder to 1.5 g. That worked nicely. I suspect the reason I needed more black powder for Phobos is that I used 1/16" styrene shear pins. Still, the components are heavier and they fit tighter than the components for Deimos. I can't tell you specifically why I ended up using 1.5 g for Phobos and 1.2 g for Deimos, just that these amounts worked. That may not be true for the rockets you build, so be sure to perform your own ground tests.

Some fliers back off on the charge size until it fails, then add a safety margin. I personally look for a charge that will fully stretch out the shock cord, but that doesn't snap the nose cone back because the shock cord was overextended.

WARNING

Always perform a new ground test if the system changes. You would need a new ground test if you changed the shear pins or significantly changed the size of the parachute or length of the shock cord, since both would change the volume in the parachute bay.

The Dual-Deploy Flight

Install the computers on the sled, prepare your squibs, and get the motor ready well before the flight. I usually do this no later than the night before the flight.

NOTE

If this is a certification flight, leave the motor assembly for the flying field. Your certifying official needs to watch you assemble the motor.

Assemble the sled, installing any tracking device and altimeters. Be sure and check each individual wire by tugging on it slightly once it is screwed into the terminal block. Wires sometimes look like they are secure when they are not. A gentle tug tells you for sure. Slide the sled into place and install the arming pin to make sure the computers are disabled (see Figure 7-22). It is very important that the computers be disarmed before you connect any black powder charges.

Figure 7-22. Install the sled. Disarm the altimeters by inserting the arming pin.

Packing the parachute is the most important part of a successful flight with a cable cutter. Wrap the parachute carefully with a flame blanket. Secure the assembly with a zip tie, installing two cable cutters so either one can cut the zip tie (see Figure 7-23). Follow the instructions that come with the cable cutters for assembling them.

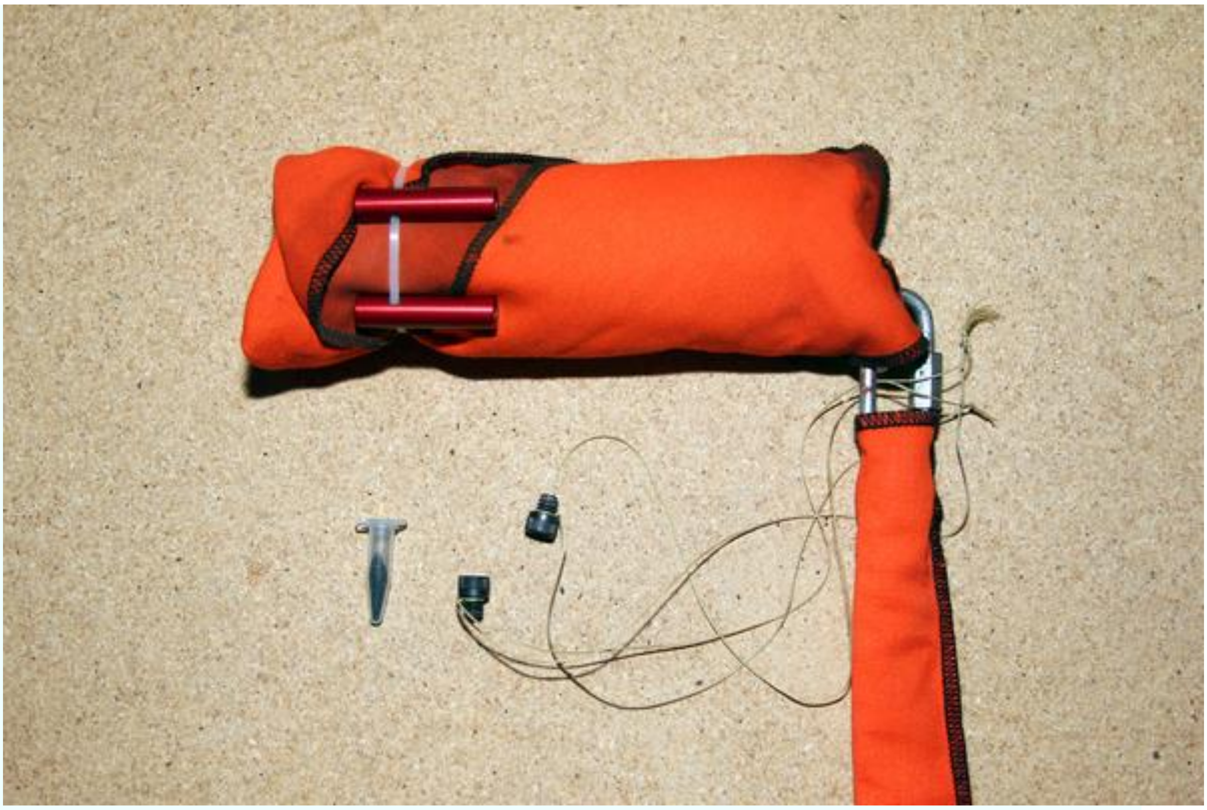


Figure 7-23. Attach the cable cutters so either one can cut the zip tie holding the parachute closed.

Connect the wires for the squibs to the terminal block for the drogue event, or apogee event. Connect the wires for the igniters in the cable cutters to the terminal blocks for the main event. Give each wire a tug to make sure it is secure. Double-check to make sure the squibs that will blow the rocket apart are connected to the apogee event, and the cable cutters that will allow the parachute to unfurl are connected to the main event (Figure 7-24).

WARNING

Make sure the wires for the ejection charges in the cable cutters are long enough that the igniters will not get tugged out of the cable cutters as the assembly flops around during descent.

Add a generous amount of tape across the bulk plate and terminal blocks. Tape the squibs on top of this layer of tape. The tape protects the terminal blocks. You can see what happens if you are not careful enough with taping in Figure 7-24. Parts of the bulkhead have been discolored by a previous ejection charge.

Slide the payload tube into the rocket, securing it with shear pins if you are using them. Screw the nose cone into place.

Install the motor.

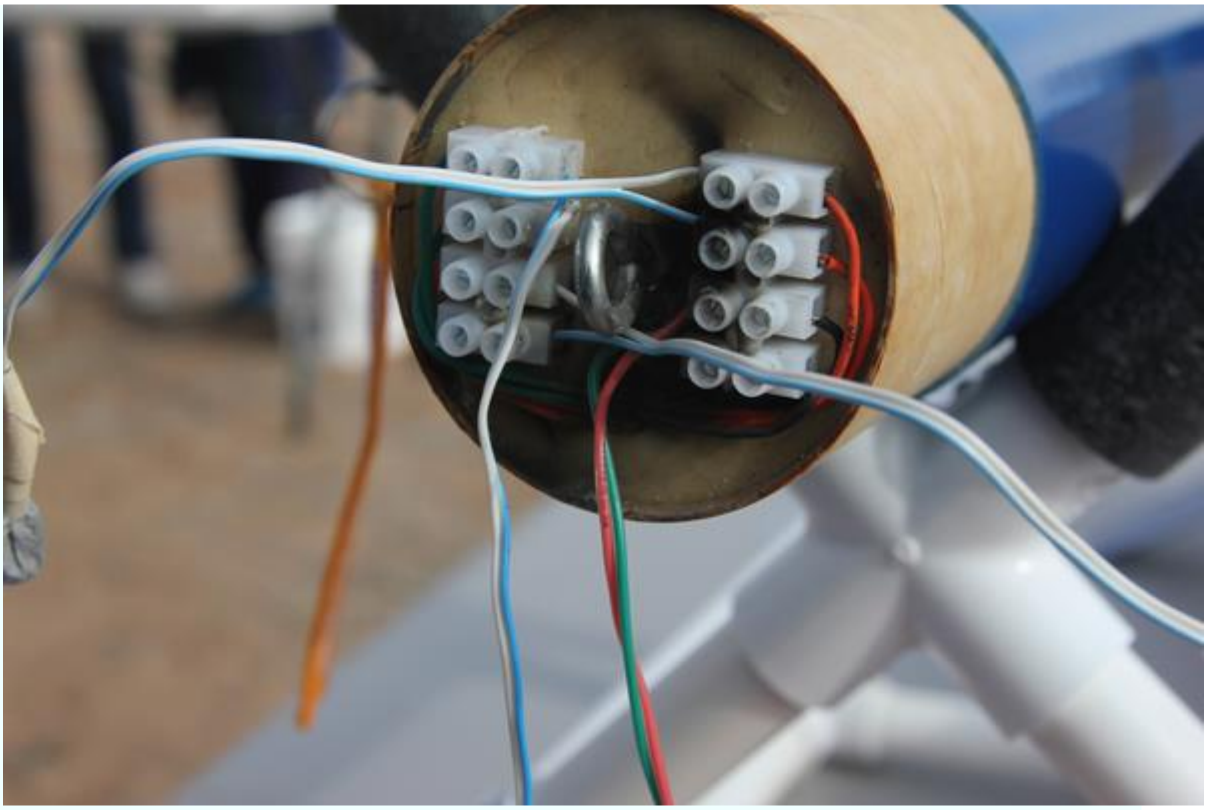


Figure 7-24. Connect the squibs to the terminal block for the apogee event, and the cable cutters to the terminal block for the main event.

WARNING

Always make sure the rocket is pointed up and ready for flight before installing the igniter. This includes arming the flight computers. That way, if the rocket takes off accidentally for some reason, the computers are ready to bring it down safely.

You are now ready for the walk to the pad, hoping you didn't forget anything. You'll find out soon enough. You did follow the checklist, though, right?

Flight Preparation Checklist

Advanced Preparation

1. Assemble the motor.
2. Assemble two squibs.
3. Install the altimeters.

Preflight

1. Install the tracking device.
2. Connect the altimeter batteries.
3. Slide the sled into the payload bay.
4. Insert the arming pin to disarm the altimeters.
5. Connect the two squibs to the apogee event terminal block.
6. Assemble the cable cutters and parachute.
7. Connect the cable cutter wires to the main event terminal block.
8. Tape the payload bay and squibs.
9. Connect the shock cord to the payload bay.
10. Insert the payload bay in the booster. Install the shear pins if needed.
11. Install the nose cone.
12. Install the motor.

Flight

1. Place the rocket on the pad.
2. Remove the arming pin.
3. Listen for audible confirmation of continuity for the ejection and cable cutter charges.
4. Make sure the launcher is in safe mode.
5. Twist the bare ends of the igniter together.
6. Insert and secure the igniter.
7. Attach the igniter clips, making sure they do not touch.
8. Test for continuity.
9. Check the tracking device.
10. Launch.

Chapter 8. Dual Deploy with a Drogue and Main Parachute

We looked at one method for dual deployment in Chapter 7. Here we'll look at a second method that uses two parachute bays. A small parachute called the drogue parachute ejects at apogee, slowing the rocket down a bit but still letting it fall fairly fast. The idea is to keep the rocket's speed low enough that the main parachute will not tear when it snaps open. The main parachute deploys at a lower altitude to slow the rocket for landing.

What Will You Need

Unlike the cable cutter method described in Chapter 7, this method requires a rocket specially built for dual deployment. Both Phobos and Deimos can be adapted for this method. While one uses fiberglass parts and the other uses paper, wood, and plastic parts, the construction is very similar. Parts lists for both rockets are included here, but I'll only show the construction for converting Deimos.

Some parts, such as wire and computers, are needed whether you are converting Deimos or Phobos, while other parts, such as body tubes, are specific to the rocket you are converting. Table 8-1 shows the parts needed for converting either Deimos or Phobos.

Part	**Description**
Altimeters (2)	Two altimeters capable of firing a main and drogue event, alo hardware to mount them. Shown are the RRC3 and the Perfec
Igniters	The text shows electric matches; Quest Q2G2 igniters work w need four for the flight and two for each ejection charge test. dozen on hand.
Sled	We'll use a sled made from 1/8”-thick aircraft plywood to hol batteries. Other materials, like plastic, also work well.

Part	**Description**
9-volt batteries (2)	Get 9-volt Duracell batteries. The brand is important, for reaso in Chapter 7.
Battery connectors (2)	9-volt battery connectors.
Switches (2)	Contact switches, such as the RadioShack model 275-016.
#2 screws (4)	1/2”-long #2 screws with nuts to mount the switches.
Terminal blocks	Get a terminal blocks strip such as the RadioShack model 274 need a total of eight terminals.
22-gauge hookup wire	At least two different colors of stranded 22-gauge hookup wir
1/8” x 0.014” brass tube	Used to form a channel for the launch pin.
0.092” piano wire	Used to form the launch pin. This must slide into the brass tub
Flag	The flag shown here is a nice, official “remove before flight” or ribbon will work just fine, too.
Quick links (3)	Get larger quick links rated for at least 800 pounds.
Tubular nylon	9/16”-wide tubular nylon shock cord. Get 20 feet.
Nomex tubing	Nomex tubing to protect the shock cord.
Parachutes (2)	Main and drogue parachutes. Sizes can vary, but 18” and 48” and 54” for Phobos is about right.
#4 1/2”-long pan head screws (3)	These will be used to secure the nose cone.

Table 8-1. Parts list for converting Deimos or Phobos to dual deplo

The parts specific to converting Deimos are listed in Table 8-2. The parts are shown visually in Figures 8-1and 8-2. Figure 8-3 shows the computers used in the text, although you may end up making changes.

Part	**Description**
Tube coupler, 9" long	PML sells tube couplers in a 36" length, so you can cut whatever you need.
Airframe, 3" diameter, 18" long and 1" long	This is the 3"-diameter Quantum tubing, sold in 36" lengths.
Bulk plates (2)	These two bulk plates form the shoulders for the end caps. They slip inside the tube couplers.
Bulk plates (2)	These two bulk plates form the end caps. They slip inside the airframe tubing, but not the tube coupler.
Eye bolts (2)	One for either end of the electronics bay.
Washers (2)	One for each eye bolt.
Nuts for eye bolts (2)	One for each eye bolt.
#6 threaded rod, 10" length (2)	Used to bind the parts together.
#6 nuts (6)	For the threaded rod.
#6 wing nuts (2)	For the threaded rod.
#6 spacers, about	These are sold in hardware stores, or you can cut your own

Part	Description
1/4” long (4)	from aluminum or brass tube. They should slip over the #6 threaded rod.
Nose cone	The nose cone for the rocket. PML sells a 3”-diameter, 13.25”-long nose cone. While this is part of the construction, you can reuse the nose cone from the original build.

Table 8-2. Parts list for converting Deimos to dual deploy

The parts specific to converting Phobos are listed in Table 8-3. Since Phobos is a heavier rocket, I used thicker threaded rod. You could do the same for Deimos, too.

Part	Description	Pa
Tube coupler, 9” long	Fiberglass tube coupler for 75 mm airframe tubes.	G Co
Booster airframe, 75 mm diameter, 18” long and 1” long	This is the 75 mm diameter fiberglass tubing, sold by the foot.	75 Fi
Bulk plates (2)	These two bulk plates form the shoulder for the end caps. They slip inside the tube couplers.	F
Bulk plates (2)	These two bulk plates form the end caps. They slip inside the airframe tubing, but not the tube coupler.	F
Eye bolts (2)	The eye bolt is attached to the bulk plate. It is used to attach the shock cord that holds the booster to the payload bay.	E
Washers (2)	A washer used to spread the force across the fiberglass bulk plate. Use at least a 3/16” washer.	

Part	Description	Pa
#10 threaded rod 10” length (2)	Used to bind the parts together.	Av ha on
#10 nuts (6)	For the threaded rod.	Av ha on
#10 wing nuts (2)	For the threaded rod.	Av ha on
#10 spacers, about 1/2” long (4)	These are sold in hardware stores, or you can cut your own from aluminum or brass tube. They should slip over the #10 threaded rod.	Av ha on
Nose cone	The nose cone for the rocket. PML sells a 3”-diameter, 13.25”-long nose cone. While this is part of the construction, you can reuse the nose cone from the original build.	3” Ka N

Table 8-3. Parts list for converting Phobos to dual deploy

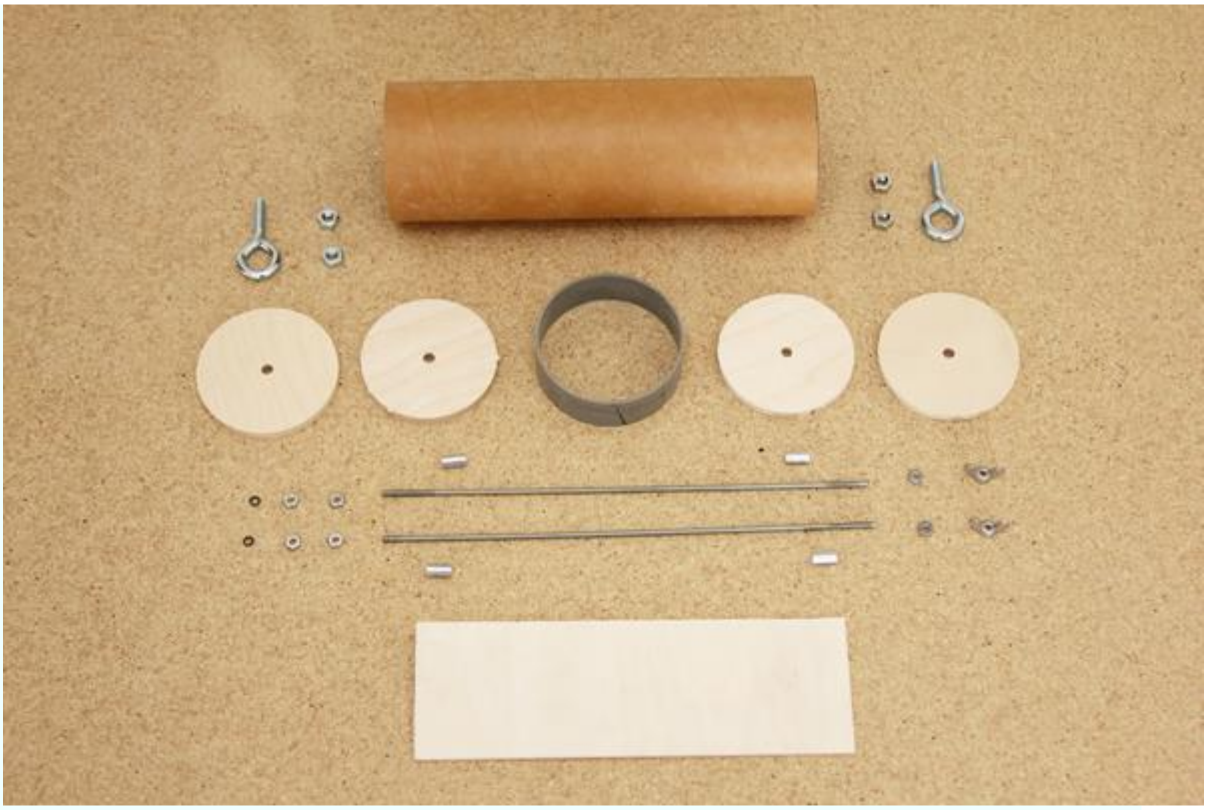


Figure 8-1. Visual parts list for the electronics bay. These are the parts to make the bay itself.

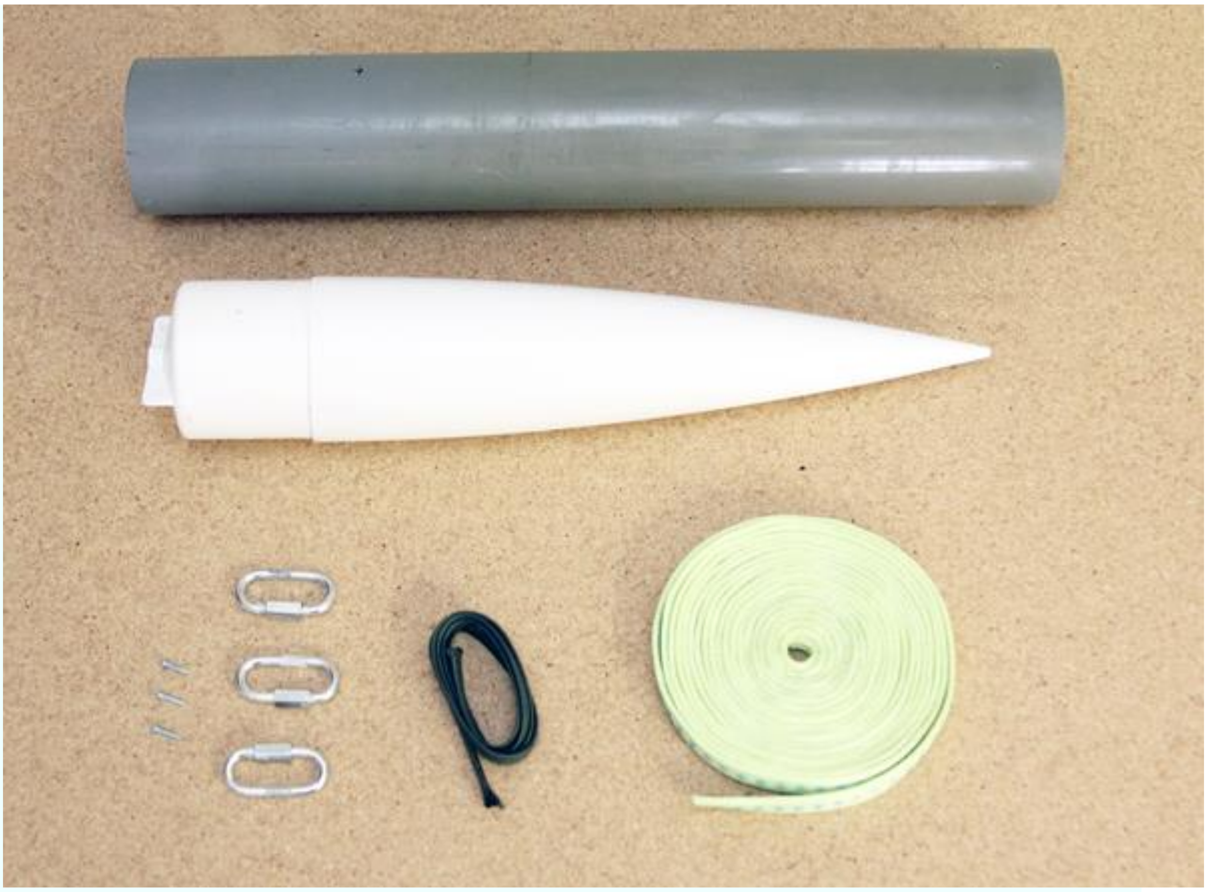


Figure 8-2. Visual parts list for the second parachute compartment.

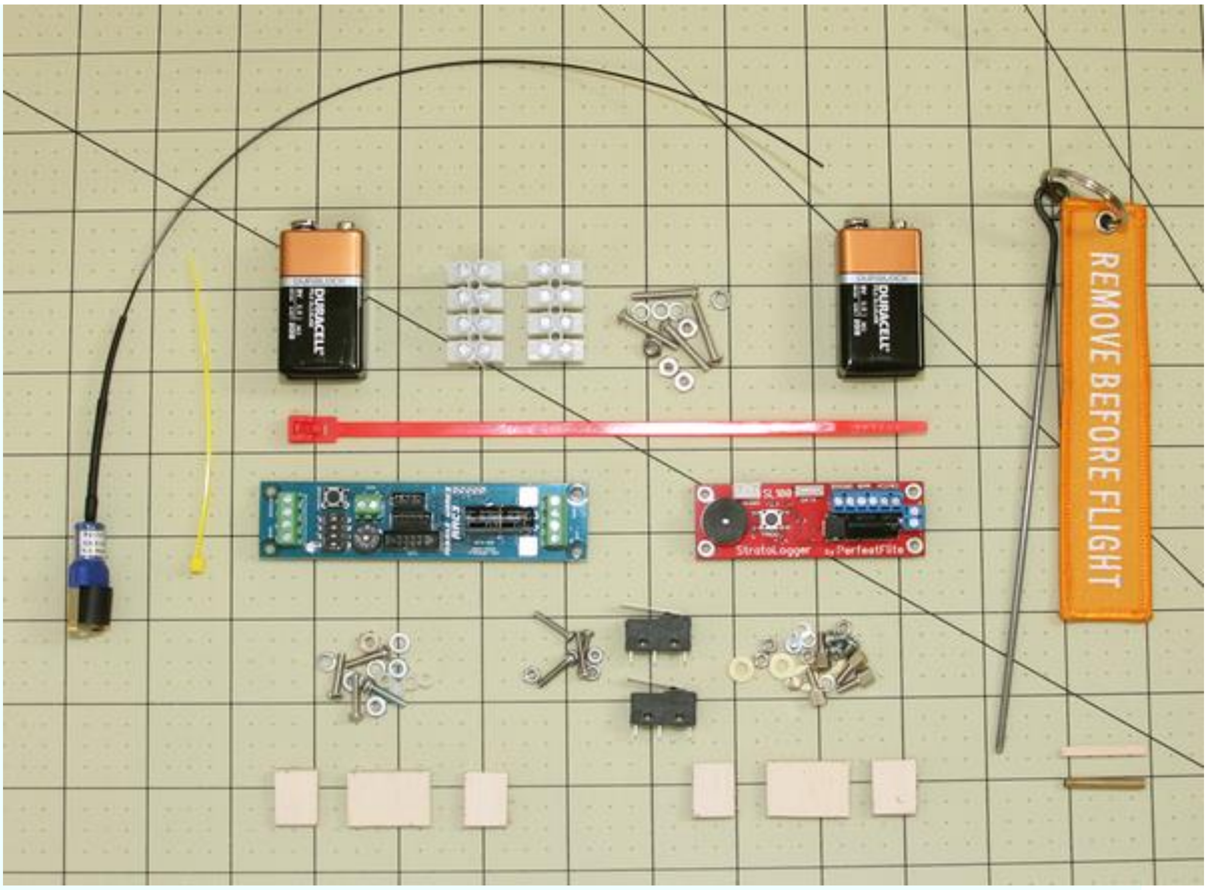


Figure 8-3. Visual parts list for the electronics that go in the electronics bay. The specifics can vary quite a bit, depending on which altimeter you use. This photo also shows a falcon radio tracker.

How Dual Deploy with Two Parachutes Works

A lot of the information from Chapter 7 applies equally to this chapter, and won’t be repeated here. While you can skip the sections specific to using a cable cutter, you should read Chapter 7 before reading this chapter.

Larger rockets, or rockets with larger motors, are heavy enough that they might not slow down sufficiently for a main parachute to open safely without a drogue parachute. While it is possible to pack a drogue parachute into the same tube as a main parachute using the approach outlined in Chapter 7, it’s more common to design larger rockets for dual deployment using two separate parachute bays. Each works pretty much like a standard parachute bay. One deploys a small drogue parachute at apogee to slow the rocket down enough for the main parachute to deploy safely—usually about 50–75 feet per second, depending on the strength of the main parachute and the weight of the rocket. The second parachute deploys at 500–1,000 feet to slow the rocket down for a soft landing, usually with a speed somewhere in the 10–25 feet per second range.

This is done with what looks like a rather odd configuration until you get used to it. Figure 8-4 shows the general layout of a typical dual-deploy rocket. The figure itself is from the OpenRocket simulation of Phobos after conversion. The electronics bay with the altimeters sits in the middle of the rocket, with a parachute bay on either side.

While this may seem odd if you are accustomed to the idea of the payload going on top of the rocket, it makes a lot of sense. Putting the electronics in the middle means there are no wires to run from the electronics to far-off locations on the rocket. It's all self-contained in one nice, neat package. The ejection charges sit on the top and bottom of the canister. One charge fires at apogee to deploy the drogue parachute, and the other at a lower altitude to deploy the main.

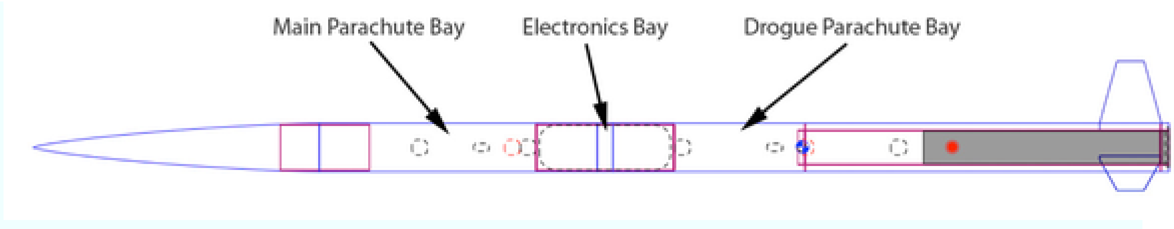


Figure 8-4. Dual deploy using two parachutes.

Converting Deimos for Dual Deploy

There are three major steps in converting Deimos or Phobos for dual deploy with two parachute bays. The steps are identical for both rockets, so you will only see the conversion for Deimos shown here. There are notes when the construction differs. Be sure to follow normal precautions for working with fiberglass if you are converting Phobos. Working with fiberglass was covered in Chapter 6, during the construction of Phobos.

Building the Electronics Bay

The electronics bay sits between the two parachute bays. It holds the altimeters and ejection charges.

Start by test fitting the four bulk plates. Make sure the two smaller plates fit into the tube coupler, and the two larger ones fit into the body tube.

Glue a small bulk plate in the center of each large bulk plate using fast-curing epoxy. Make sure the smaller plates are exactly in the center of the larger ones.

As shown in Figure 8-5, drill a 1/4” hole in the center of each bulk plate assembly for the eye bolt. Drill two 5/32” holes 15/16” from the center hole, placing the three holes in a line. These holes are for the threaded rod.

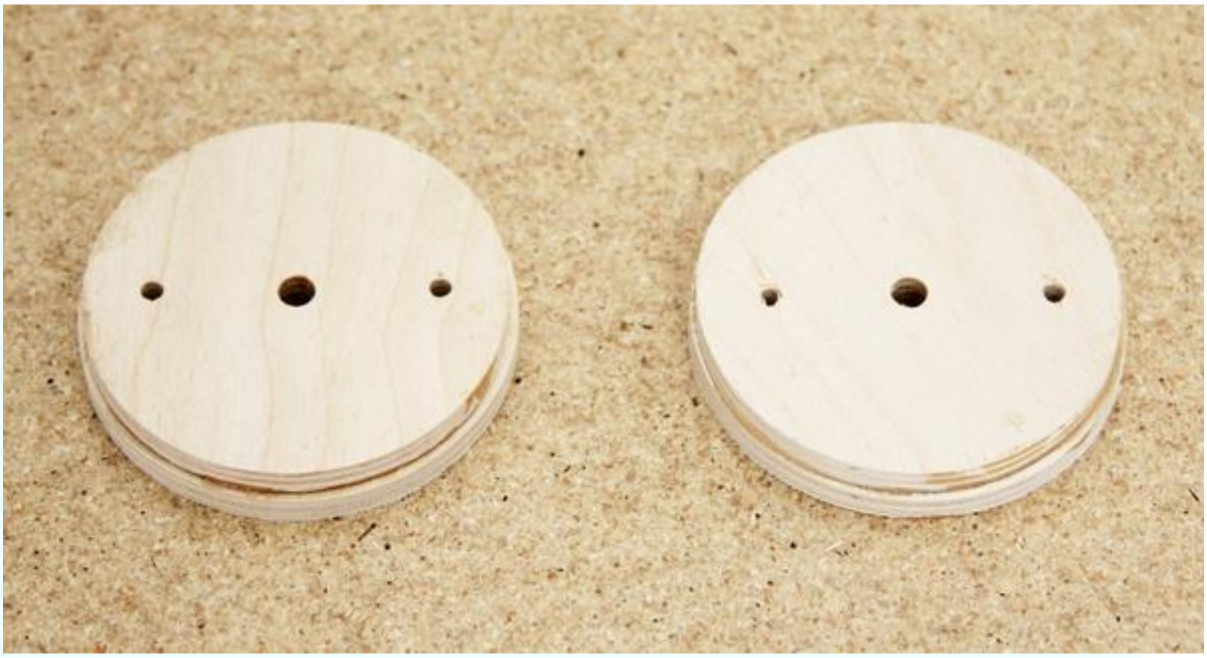


Figure 8-5. Glue the bulk plates together. Drill a 1/4” hole in the middle, and two 5/32” holes 15/16” from each center hole.

You will need to adjust these hole sizes if you use different eye bolts or a different size threaded rod. For example, since the Phobos parts list calls for #10 threaded rod rather then #6 threaded rod, the two outer holes should be 7/32” rather than 5/32” in diameter.

Cut a 1”-long piece from the airframe tube. Make sure the ends are perfectly flat. One way to do this is to slip the tube coupler into a long piece of airframe tube, slip the 1” piece over the coupler, and rotate the two tubes. If you can rotate the tubes without seeing gaps between them, both are flat. If not, you need some touch-up work.

Glue the 1” piece of airframe tube in the center of a 9”-long section of tube coupler (see Figure 8-6).

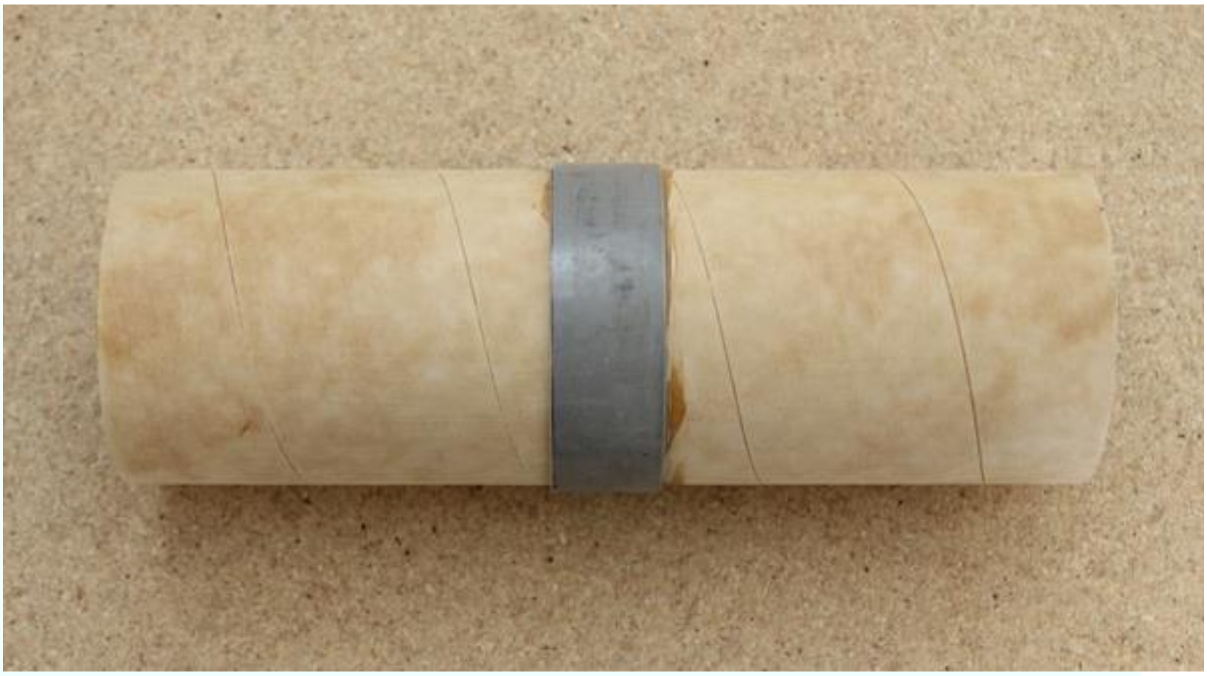


Figure 8-6. Glue a 1” piece of body tube in the center of the tube coupler.

Drill three 1/8” vent holes, evenly spaced around the 1” airframe tube (see Figure 8-7). These vent holes allow the air pressure to equalize inside the payload bays, and are essential to the functioning of the altimeters. See “Finding Altimeter Vent Hole Sizes” for details about altimeter vent holes.

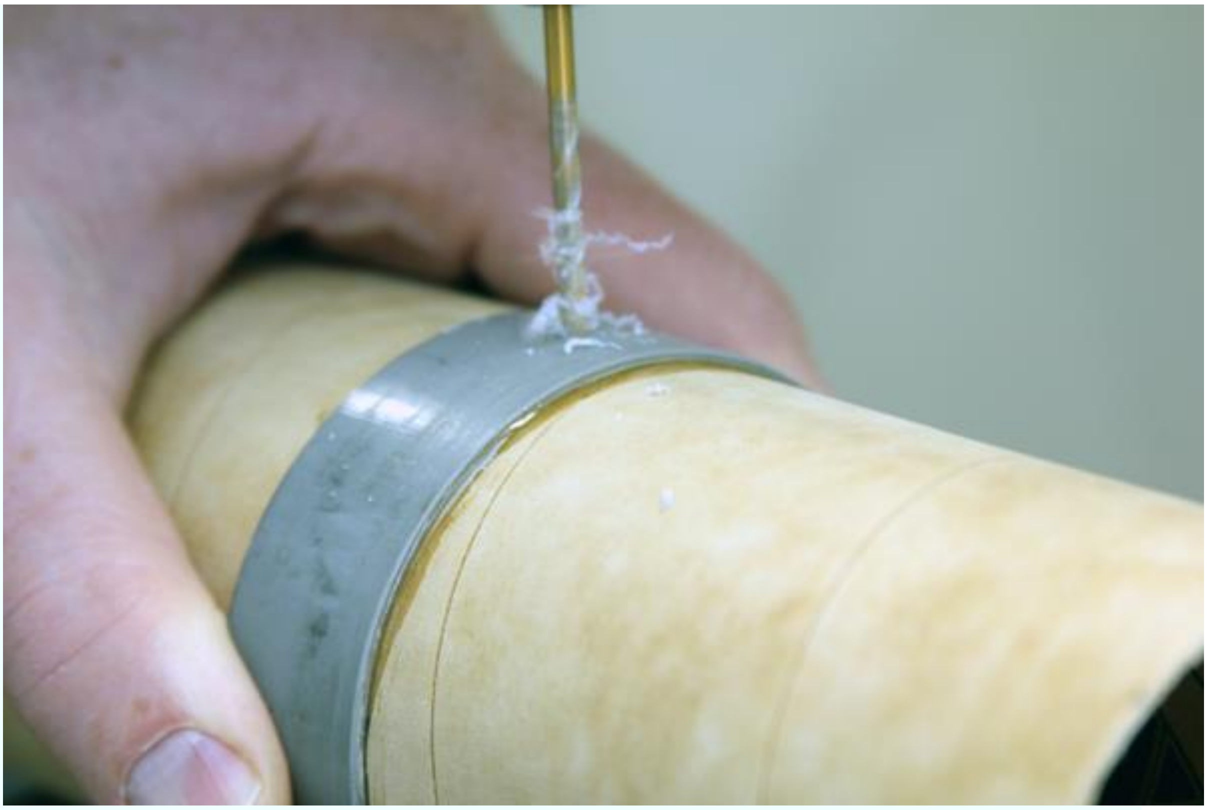


Figure 8-7. Drill three altimeter vent holes.

Cut a piece of 1/8” aircraft plywood or some similar material to form a sled. The sled should be 2 3/4” wide and 8 1/2” long for Deimos. The sled for Phobos is also 2 3/4” wide, but it will be 8 3/4” long. The sled should fit snugly in the electronics bay, touching each bulk plate, but the bulk plates must be able to fit snugly in the bay. Adjust the length if needed to fit your components.

The sled won’t be quite as wide as the inside diameter of the tube coupler because it won’t be in the exact center; this sled will ride on top of two threaded rods that will slip through the 5/32” holes in the bulk plates.

Cut notches at the ends of the sled, as seen in Figure 8-8. These notches should be large enough to allow for the nuts and bolts that will protrude through the bulk plates. Since the specific nuts you use may vary, the size of the slots may vary, too. In my case, the central slot is 1/2” wide and 1/4” deep. The two outer slots are centered 15/16” from the middle of the sled, right over the 5/32” holes in the bulk plates. Each slot is 3/8” wide and 3/16” deep.

Figure 8-8. Cut the sled from 1/8" aircraft plywood or a similar material.

Cut two 10"-long pieces from a #6 threaded rod. You can buy threaded rod from most hardware stores. It's fine to substitute #8 or even #10 threaded rod, but the smaller rod is plenty strong enough, and gives you a bit more room to work. Use #10 threaded rod for Phobos, since the rocket is heavier.

Assemble the interior of the sled. Use four nuts to fasten the threaded rod to one bulk plate, as seen in Figure 8-9. Slide two spacers onto each threaded rod. Use two nuts and two wing nuts to fasten the other bulk plate to the opposite end of the threaded rods.

Tape the sled to the threaded rods, tightening the nuts until the sled is sandwiched between the two bulk plates.

Slide the spacers until they are 3/8" inch or so from the end of the bulk plate. Apply some scrap cloth across the top of each spacer as a form for the glue, and then use slow-curing epoxy to glue the spacers to the sled (see Figure 8-9). The slow-cure epoxy will give you time to glue all four spacers and make sure the alignment is perfect before the glue starts to set.

Once the glue dries, screw the remaining hardware in place (see Figure 8-10). One side of the sled gives you a nice, flat work area for installing altimeters, batteries, radios, and the like, while the other size has some usable space between the two threaded rods.

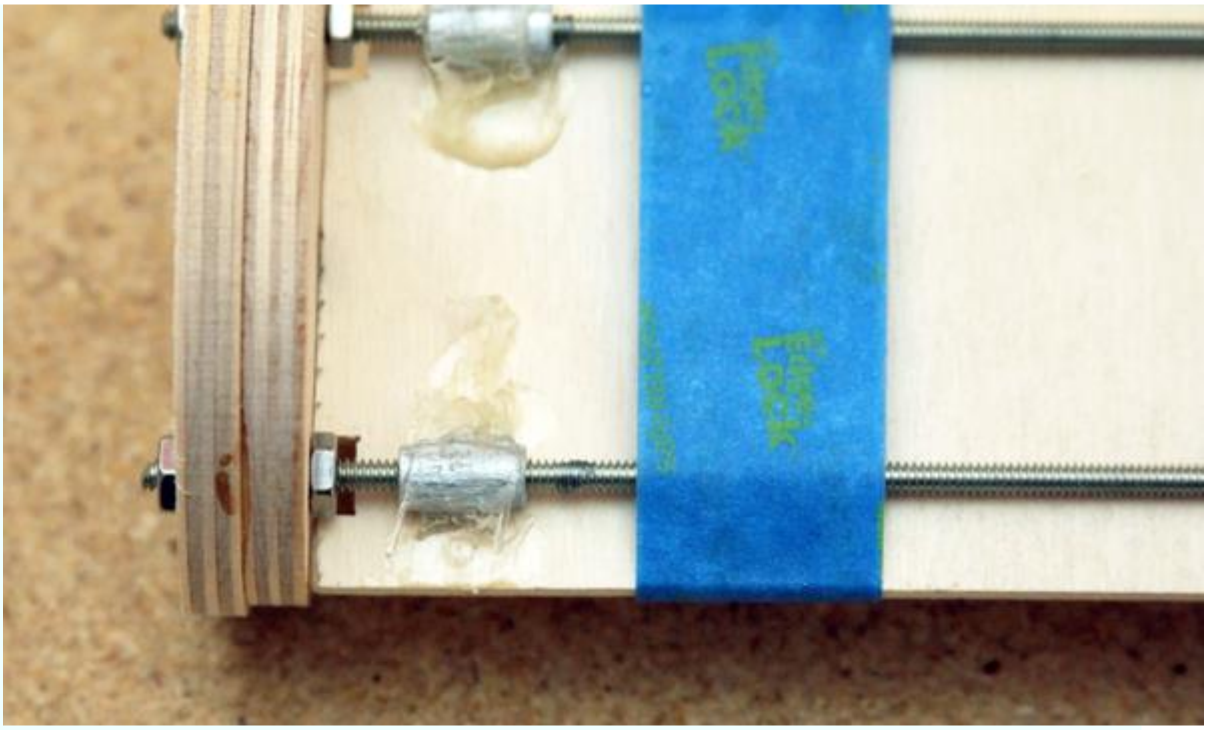


Figure 8-9. Glue the spacers in place.

Figure 8-10. Install the remaining hardware.

The wing nuts make it easy to remove one bulk plate. You can slide the tube coupler on and off to expose anything mounted on the sled while you prepare the rocket. Once you are ready, slide the tube coupler back in place and fasten the bulk plate into place with the two wing nuts (see Figure 8-11).

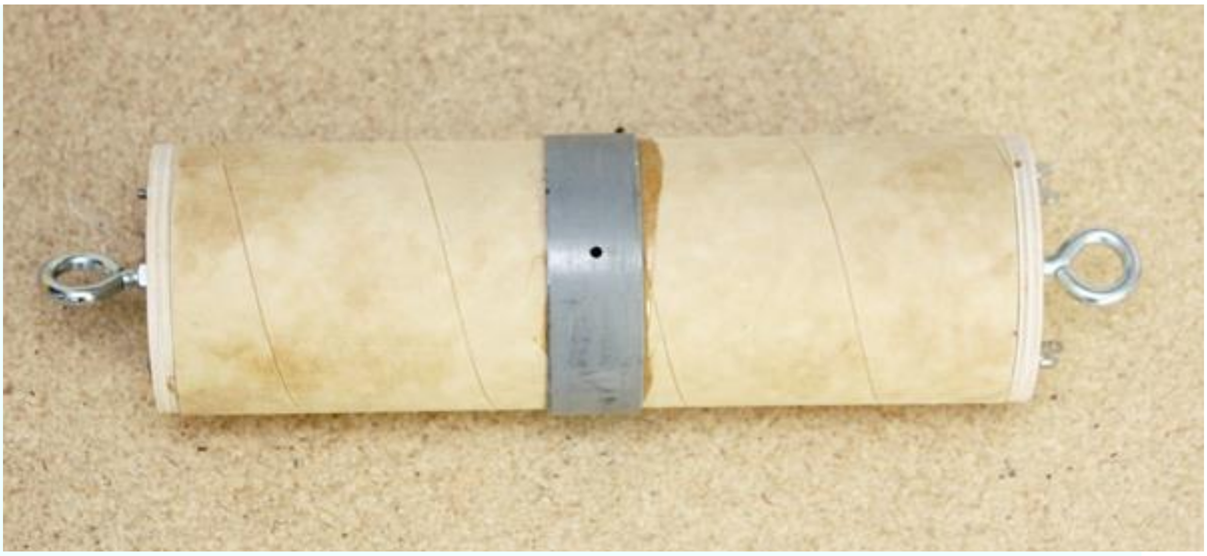


Figure 8-11. The competed electronics bay, ready to slide into the rocket.

Building the Second Parachute Bay

The second parachute bay is just a body tube above the tube coupler. Since there will be a second parachute, you will also need a second shock cord and hardware. While the parts list includes a nose cone, you already have a nose cone if you built your rocket with a standard payload bay. It’s easy enough to reuse that nose cone on this version of the rocket.

Build the shock cord first. Cut 20 feet of 9/16” tubular nylon. Attach three quick links rated at 800 lb, one at each end of the shock cord and one about 1/3 of the way from one end of the shock cord. Refer back to “Installing the Quick Links” for detailed instructions on tying knots and so forth. You can optionally add a few feet of Nomex tubing to one end to protect that end from the ejection charge.

You will need some way to fasten the shock cord to the base of the nose cone. There are several options. The plastic nose cone for Deimos has a tab on the bottom that can be used to attach the shock cord, but I didn’t trust it to be strong enough. I took the nose cone to my local hardware store to find a screw eye that would fit. While your nose cone’s size may vary a bit, I found that a #2 screw eye, made from 0.264” wire with an overall length of 2 1/2”, gave a very nice, snug fit. Once I screwed it in place, I was confident the shock cord would stay attached to the nose cone.

Phobos is a bit different. While your nose cone may vary slightly, many fiberglass nose cones are made with a metal tip. The tip is threaded for a bolt, which holds the tip to the top of the nose cone by tightening it down onto a washer. Remove and discard that bolt. It is probably a 1/4-20 bolt, but take the nose cone tip to the hardware store to be sure. I found a welded eye bolt with a 1/4-20 thread, added a nut to press up against the washer (see Figure 8-12), and reassembled the nose cone with the eye bolt in place. It provides a perfect attachment point for the shock cord, although you have to remove the tip to attach and detach the shock cord.

Cut an 18”-long section of body tube for the upper parachute bay. Drill three 1/8” vent holes evenly spaced around the tube, 5” from the end you’ve picked to be the bottom of the tube.

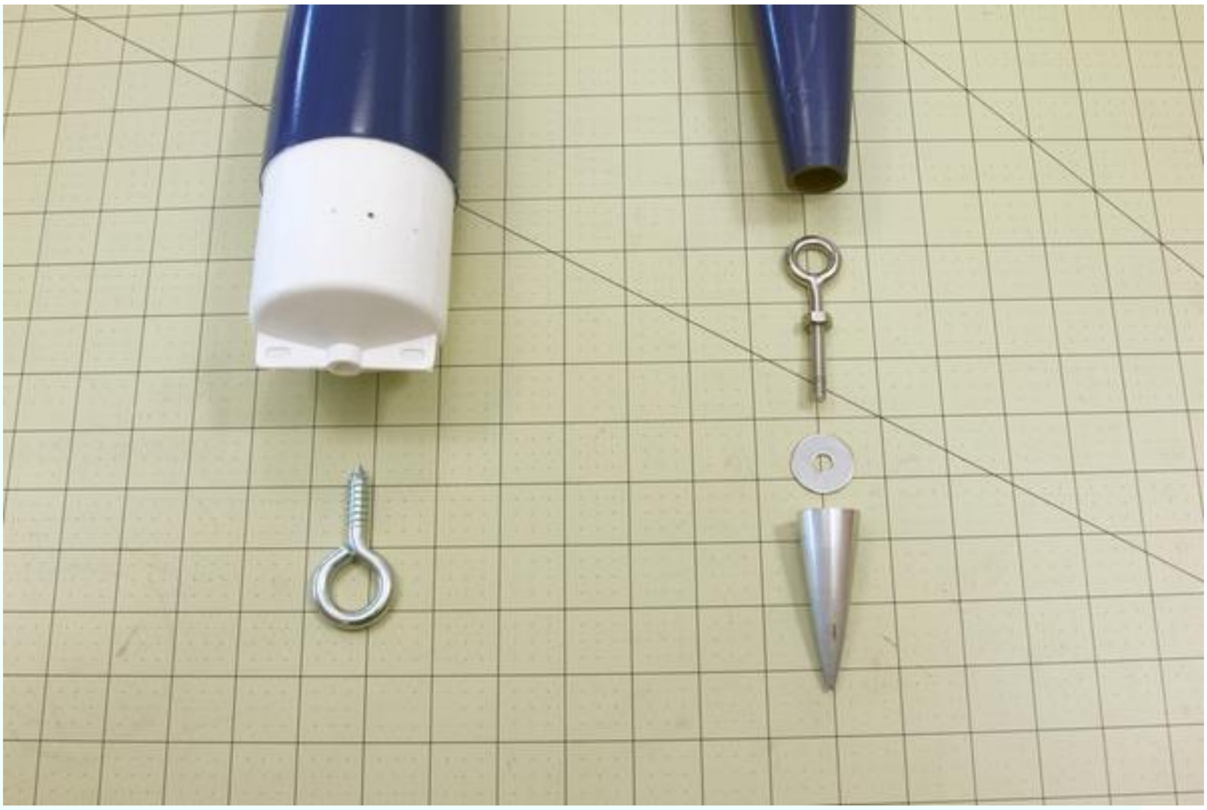


Figure 8-12. Find a secure way to attach the shock cord to the nose cone.

Just as with the original payload bay from Chapter 6, we will use screws to fasten the nose cone into the top of the parachute bay. That’s easy if you are using a new nose cone. I’m going to assume you used the same nose cone for both configurations, though. That leaves you with a bit of a problem. Unless you are fortunate enough to have accurate machining tools, the three holes used to hold the nose cone in place in Chapter 6 are not exactly 120° apart, and not exactly the same distance from the end of the body tube. There is only one way the nose cone will fit into the body tube and allow the screws to hit the holes in both the body tube and the nose cone. How can we drill holes so the same body tube will fit the holes in the old nose cone?

One easy and surprisingly effective way to get the holes in the same place twice is to wrap a sheet of paper around the old body tube. Fit it carefully to the end of the tube, and then use a pencil to poke holes through the paper and into the existing drill holes in the body tube.

Wrap the paper around the end of the new body tube and use a permanent marker, as seen in Figure 8-13, to mark the hole locations. Drill your pilot hole for the machine screws used to hold the nose cone in place as precisely on these marks as you can. I’ve done this for several rockets, and have had no trouble moving the nose cone from one body tube to another.

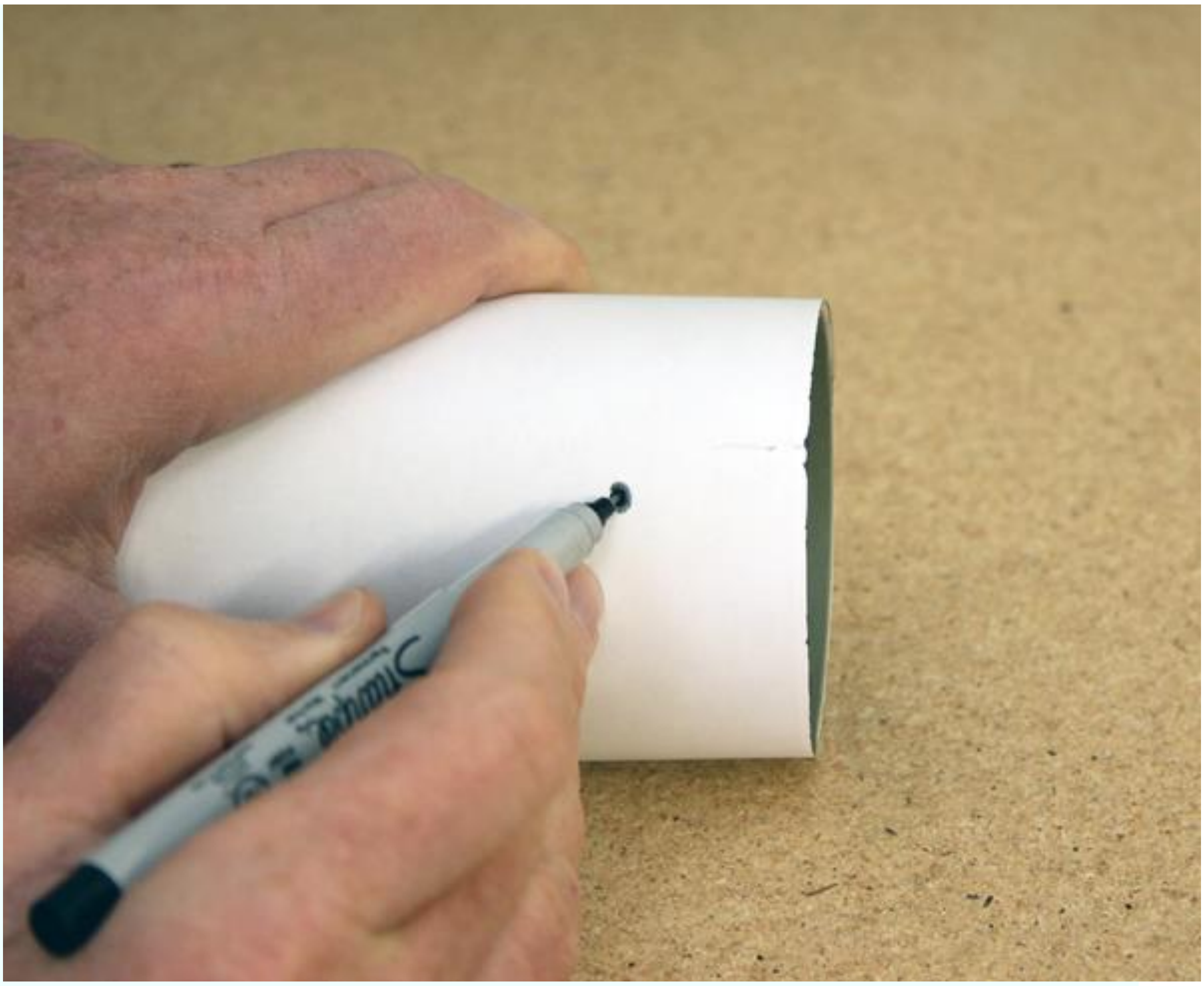


Figure 8-13. To drill holes in the same place on two body tubes, place a sheet of paper on the tube with existing holes and punch through the paper over the holes. Transfer the paper to the new tube and mark the hole locations for drilling.

Whether you are using the same nose cone on two body tubes or a new nose cone, drill three 7/64”-diameter holes evenly spaced around the top of the body tube. Attach the shock cord to the base of the nose cone, slip the body tube over the shock cord, and use three 1/2”-long #4 screws to fasten the nose cone in place.

If you recall from Chapter 6, I opted for 1/16” styrene rods as shear pins on Phobos, but didn’t use them on Deimos. Once you move to dual deploy with two parachute bays, though, you really need shear pins on any rocket. This helps prevent the first ejection charge from pulling the other parachute bay open when the shock cord snaps taut. Drill the holes for the shear pins through the main parachute bay tube and into the electronics bay.

As you know, it is rare to get all of the holes lined up perfectly when drilling by hand. Mark the components so you can realign them easily. Once the rocket is painted, you might add alignment marks like the ones you see in Figure 8-14. The triangle points up, while the line allows easy alignment of the three parts of the rocket.

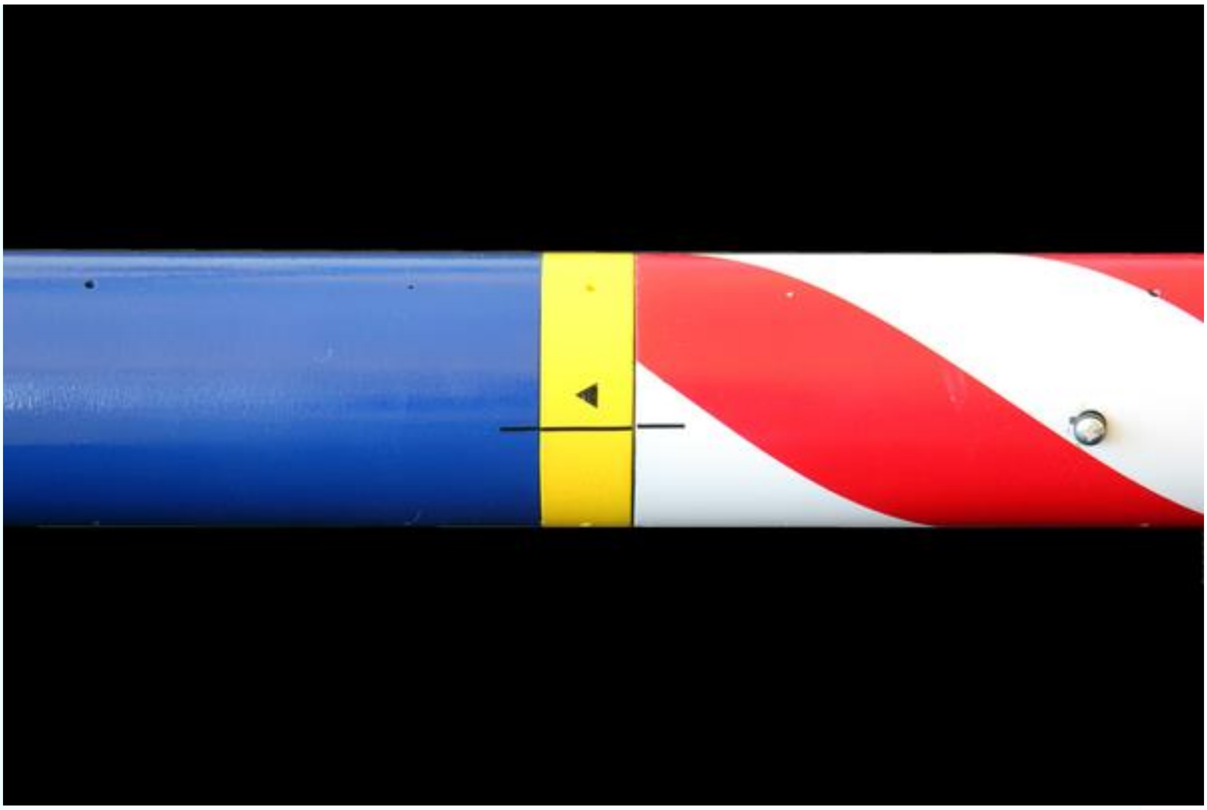


Figure 8-14. Place alignment marks on the rocket to make it easy to get the parts lined up.

The completed rocket is an impressive 68” long. You can see it in Figure 8-15, getting ready for its first flight at the well-equipped range in Alamogordo, New Mexico.

Figure 8-15. The author installing an igniter in a J350 motor before the first dual-deploy flight of Deimos.

Installing the Electronics

The electronics bay is assembled essentially the same way as the payload bay for the dual-deploy rocket that used cable cutters. See “Modifying Deimos or Phobos for Dual Deploy” for general wiring tips and diagrams, and “Choosing an Altimeter” for an explanation of why two flight computers should be used rather than just one.

The main difference between the payload bay for cable cutters and this electronics bay is that there are ejection charges on both the top and bottom. It really doesn’t matter which side you use for the drogue and main parachutes. Since the lower parachute bay is smaller than the upper on Phobos, I elected to put the drogue in the lower parachute bay and the main parachute in the upper bay.

Construct two battery seats from the same aircraft plywood used to build the sled itself. Each seat should be 1” by 5/8”. Add sides to support the seat. The ones shown are 1/2” by 5/8”, but you may need to adjust this size slightly to accommodate the bolt notches on your specific electronics bay. There will be two batteries; I elected to place them on opposite sides of the sled, so there are two battery seats, one on either side.

Assemble the electronics bay so the side of the sled lines up with one of the holes. Mark this hole; it will be the one you use for inserting the arming pin. Mark the side of the sled through the hole. This is the location on the sled where the arming pin will sit.

Remove the sled from the payload bay. Draw a line across the sled at the location you marked for the arming pin. Use quick-cure epoxy to glue a 1”-long section of 1/8” x 0.014” brass tube to serve as a guide for the arming pin. Be sure to glue this on a 1/16”-thick slice of wood so the arming pin slides across the center of the switches. The brass tube should be about 1/16” back from the edge of the sled to allow for the curvature of the body tube. At this point, your sled should look like Figure 8-16.

The next step is to decide exactly where each component will be placed. Figure 8-17 shows the almost completed sled with the components I selected attached. Here you see a Missile Works RRC3 altimeter as the main computer, backed up by a PerfectFlight StratoLogger. As discussed in Chapter 7, there are two RadioShack model 275-016 switches and two batteries for complete redundancy. A falcon tracker radio sits near the top of the sled, with its antenna draping below. The arming pin, made from 13-gauge (0.092”-diameter) piano wire, is in place, holding the switches in their open position.

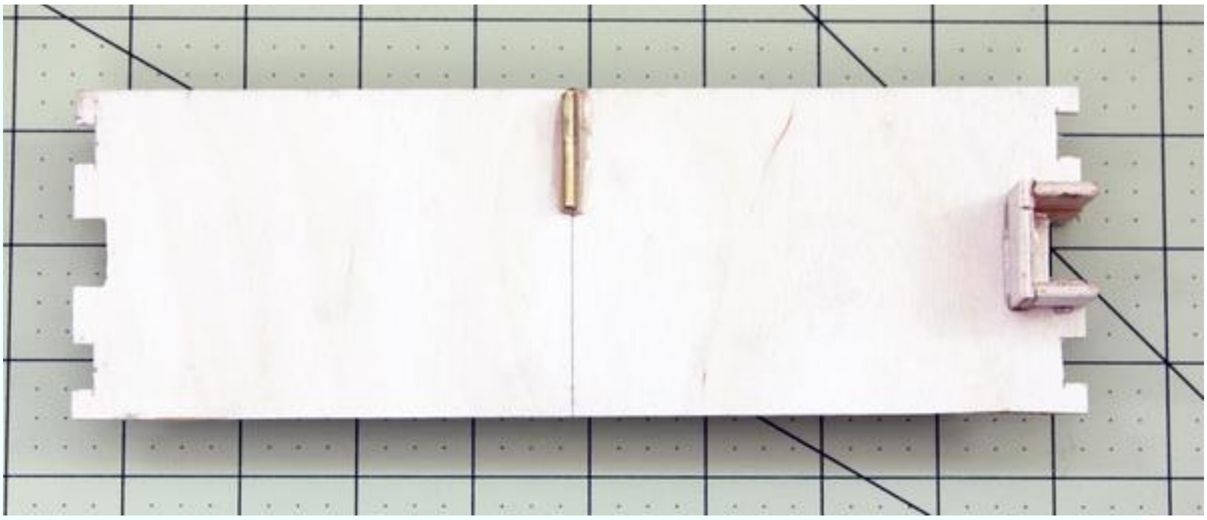


Figure 8-16. Install the guide for the arming pin and the seats for the two 9-volt batteries.

Mark the appropriate locations for the altimeters and accessories you're going to use and drill appropriate holes for the mounting screws and wiring.

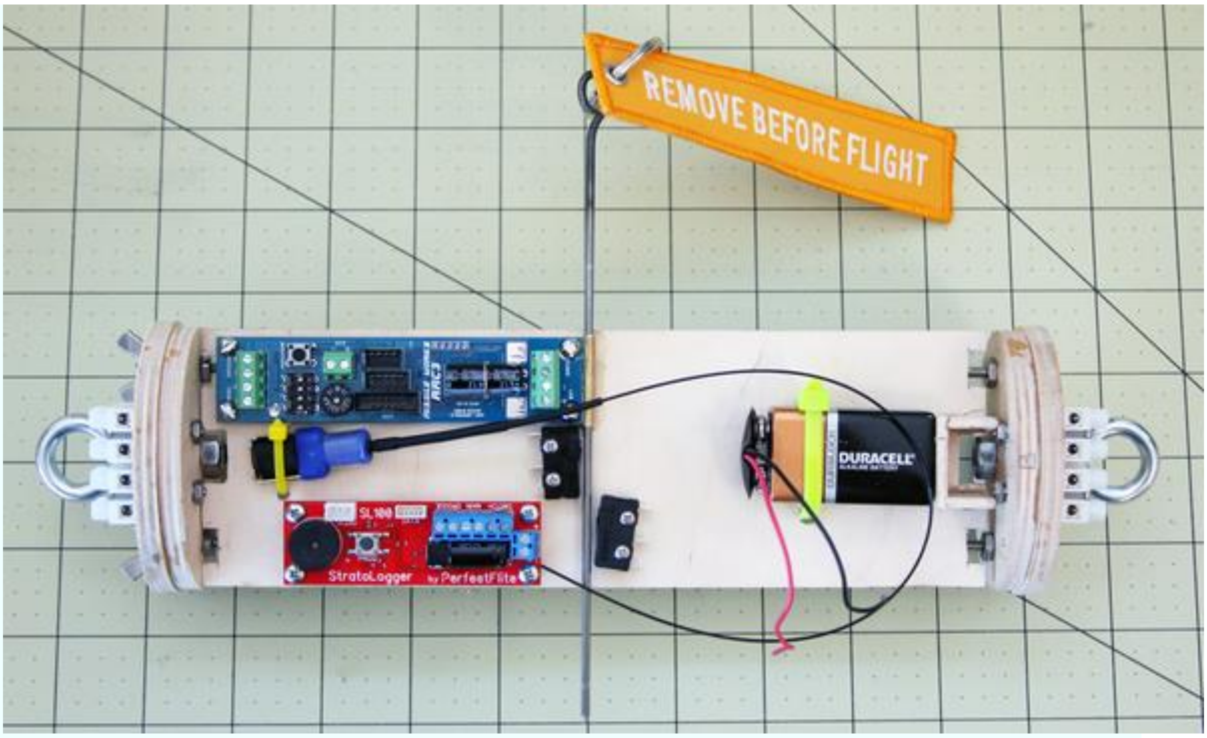


Figure 8-17. Select positions for the components you want to mount on the sled. Drill appropriate holes for the mounting screws.

Connect the various components on the sled by soldering the switches and 9-volt battery connectors, and tinning the ends of the wires that will connect to the altimeters. Use 22-gauge hookup wire, either stranded or solid, for the connections on the sled.

Mount two four-connection terminals, one on the top bulk plate and one on the bottom. You can use screws or epoxy to mount the terminals. Shown are terminals cut from a 12-terminal strip sold by RadioShack, model number 274-680.

Drill a 1/8" hole in the top and bottom bulk plates. Cut four 15"-long pieces of #22 stranded wire. Use two colors of wire, cutting two pieces of each color. Tin the ends of these wires. Connect one end of each wire to the terminal blocks on the bottom bulk plate. Pull the wires through the hole. Apply fast-cure epoxy to the wires and hole to seal the hole shut. It is important that the ejection charge gases not have a path through the hole, since they can harm the altimeters.

Repeat this process with four 6”-long strands of wire on the top bulk plate.

The completed wiring is shown in Figure 8-18. Note that the sides for the battery seat have been trimmed back to accommodate the mounting screws for the terminal blocks.

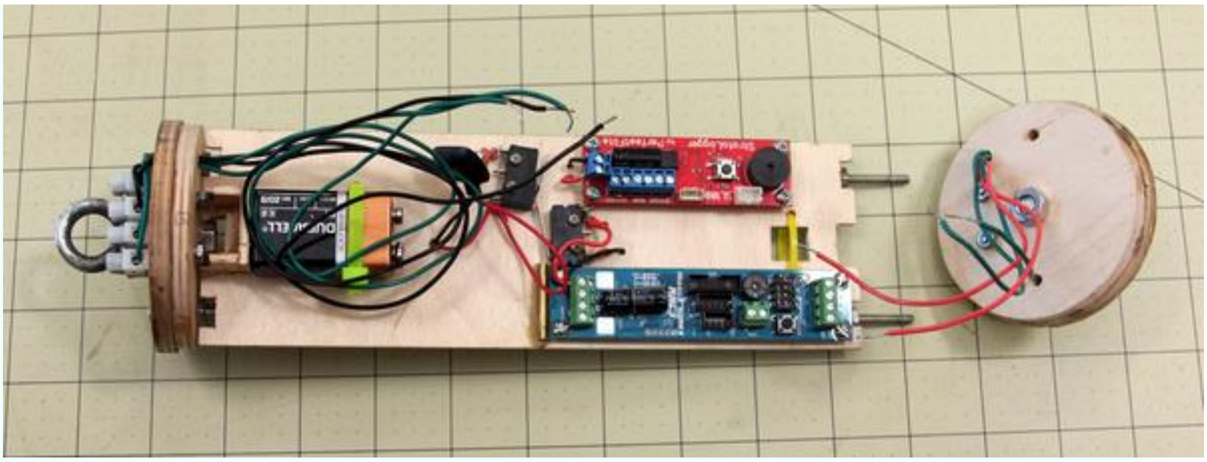


Figure 8-18. Wire the components using #22-gauge hookup wire.

Testing the Ejection Charge

See “Picking the Size for Recovery Charges” for general comments on ejection charge testing and selecting the size for black powder ejection charges.

My tests showed that 1.2 g of FFFFG black powder was appropriate for the upper parachute bay on Deimos (see Figure 8-19), but I needed 1.5 g for the lower bay. Phobos needed 1.5 g of black powder for both bays. Your results may vary depending on the construction of your rocket and the type of shear pins you select, so be sure to conduct a test with your rocket.

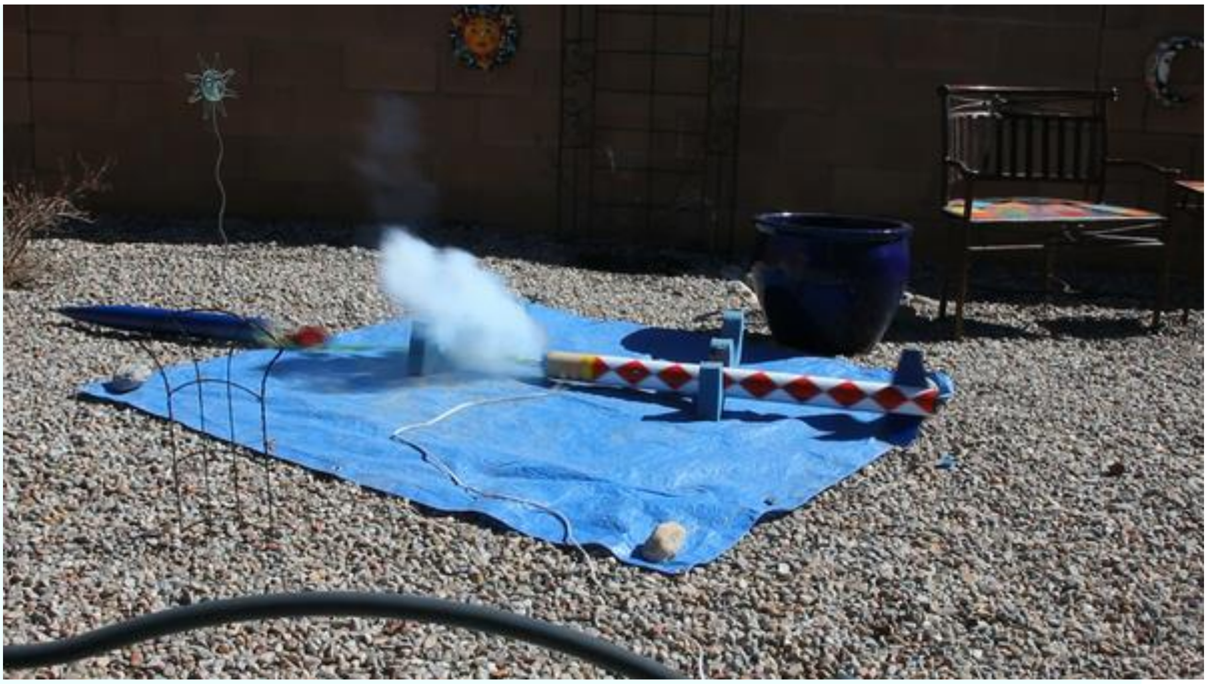


Figure 8-19. Upper bay ejection charge test for Deimos. The parts are still very much in motion in this frame, taken from a movie of the test.

Flying a Dual-Deploy Rocket

Install the wiring and tracking devices in the electronics bay. Secure the bay with the wing nuts and install the arming pin to disarm the altimeters.

Connect the ejection charge squibs to the top and bottom bulk plates. Use tape on the bulk plates, under the charges, to protect the bulk plates, and tape over the charges to keep them in place during flight.

You can clearly see the discoloration from the ejection charge tests in Figure 8-20.

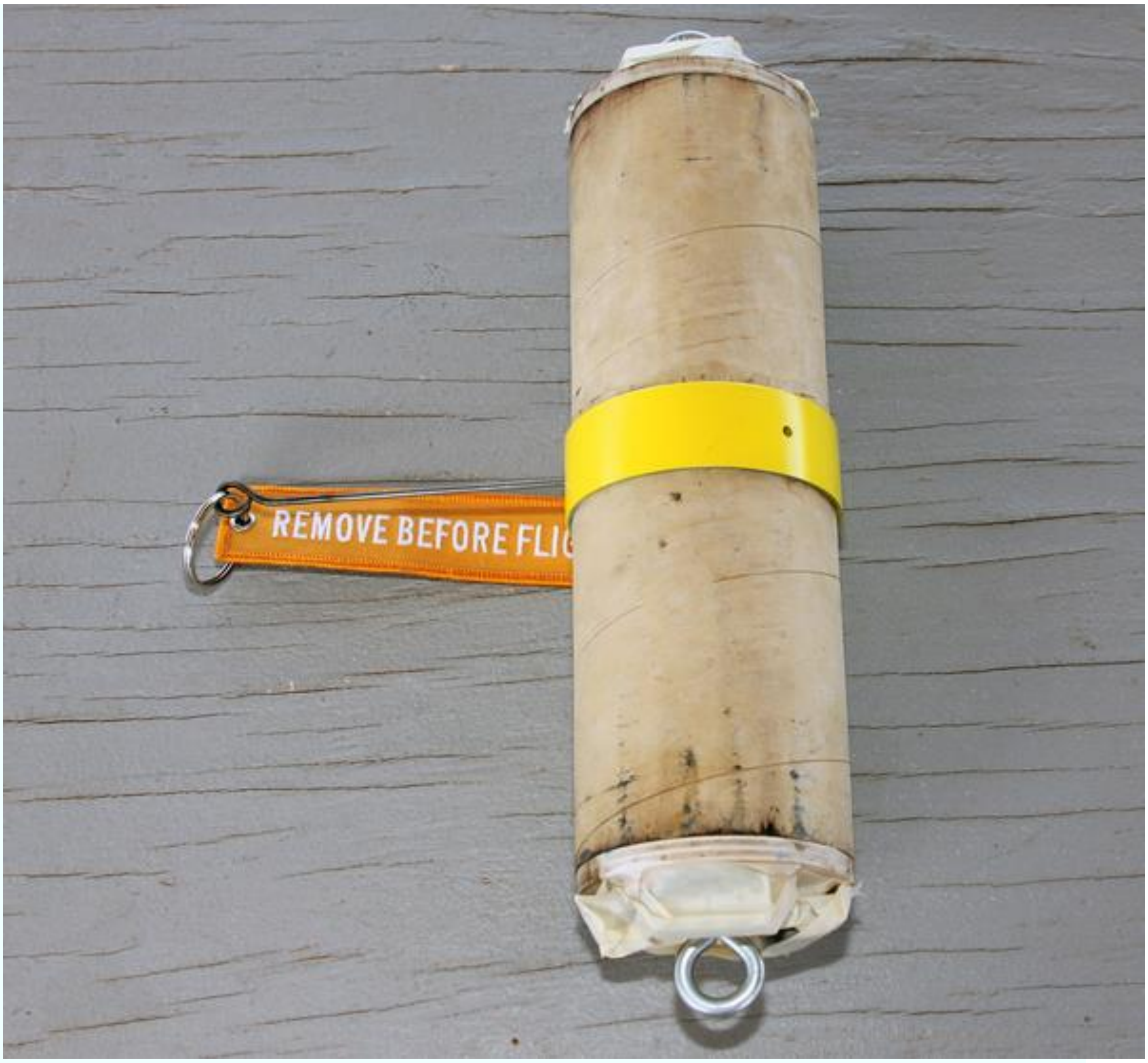


Figure 8-20. Connect the electronics and insert the arming pin first, then install the black powder charges.

There isn’t a lot of room for the parachutes. Coil the shock cord in sections that give about 2 1/2”-diameter rolls, securing these with painter’s tape. The shock cord takes up less room this way, and the tape will not prevent a lively ejection charge from stretching out the shock cord (see Figure 8-21).

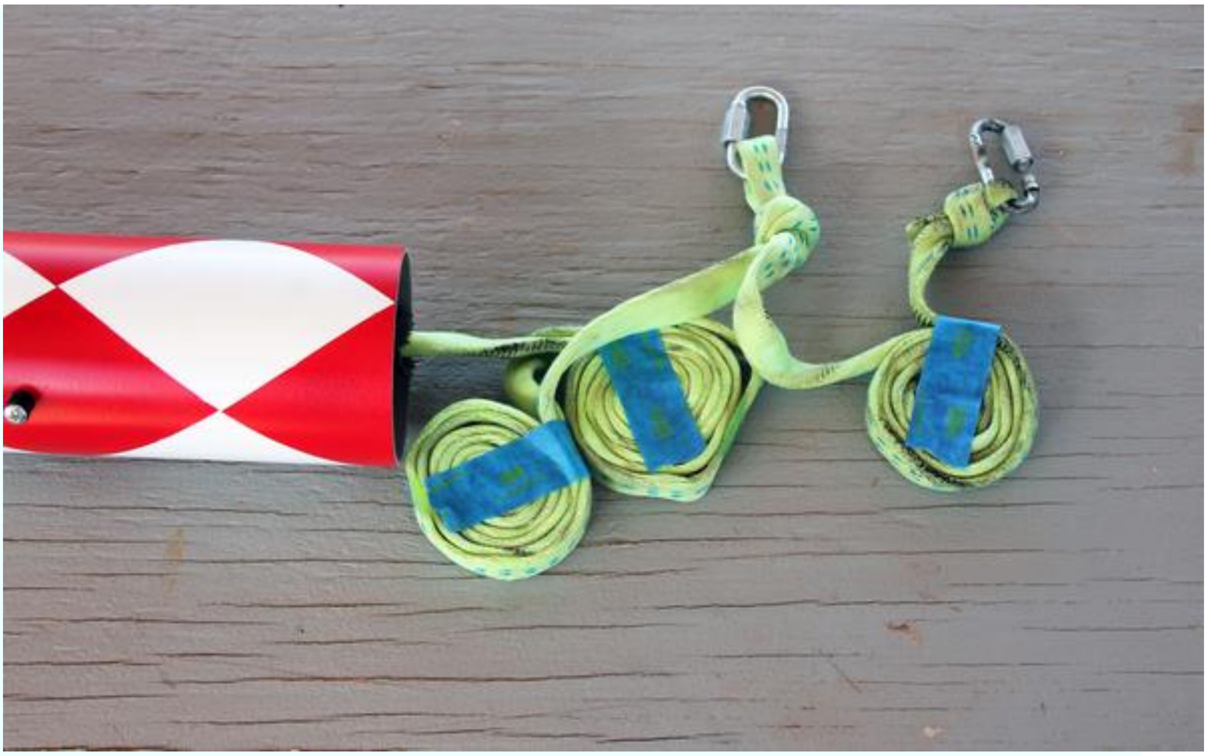


Figure 8-21. Tape the shock cord in small rolls so it takes less room in the parachute bay.

Fold the drogue parachute and wrap it in a flame blanket. Attach the bundle to a quick link 1/3 of the way from the end of the shock cord. Attach the end of the shock cord to the bottom eye bolt on the parachute bay (Figure 8-22). I used an 18” drogue parachute for Deimos and a 24” drogue parachute for Phobos. The idea is to slow the rocket down enough so the main parachute will not tear when it opens.

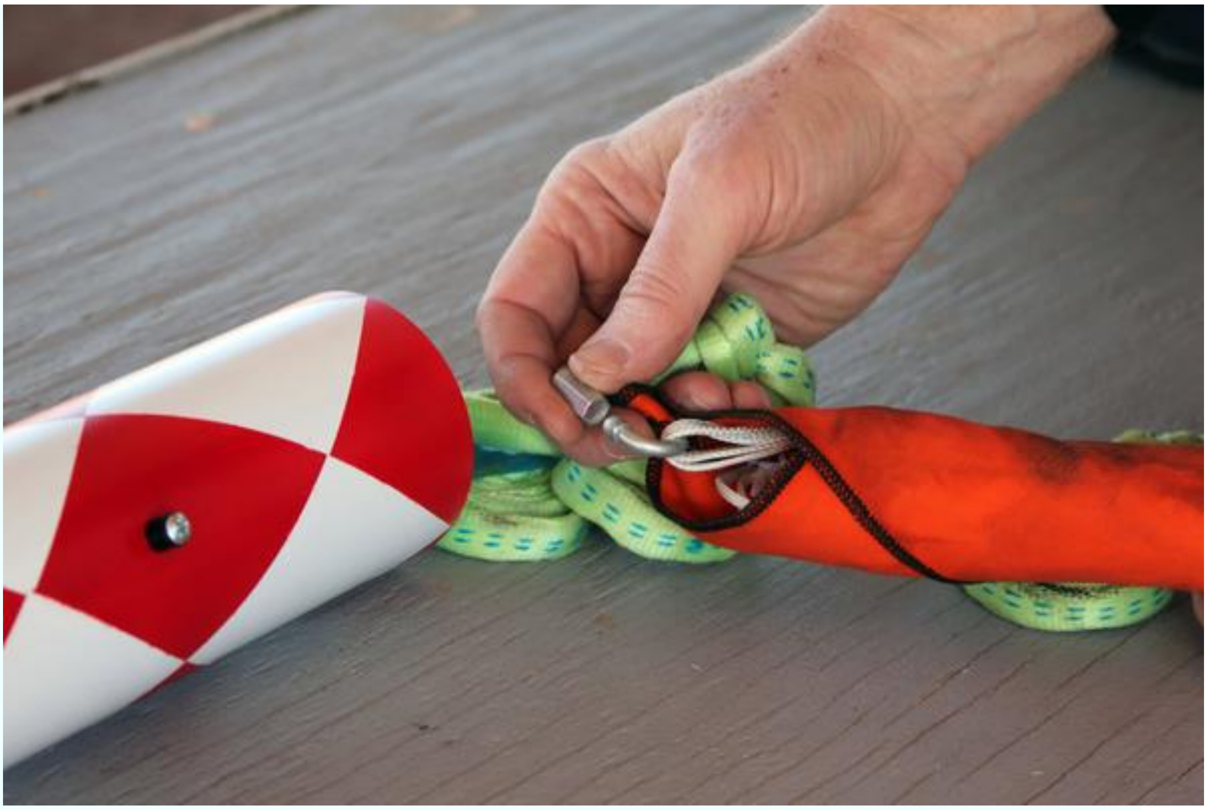


Figure 8-22. Prepare the drogue parachute.

Repeat the process with the main parachute. I used a 48” parachute for Deimos and a 54” parachute for Phobos.

At this point you can install the shear pins and then the motor.

Place the rocket on the launch pad. Pull the arming pin and listen to the beeps from the altimeters to verify continuity. Install the igniter and check for continuity. Check the tracking radio to make sure you have a good signal. You’re ready for launch!

Flight Preparation Checklist

Advanced Preparation

1. Assemble the motor.
2. Assemble four squibs.
3. Install the altimeters.

Preflight

1. Install the tracking device.

2. Connect the altimeter batteries.
3. Assemble the electronics bay.
4. Insert the arming pin to disarm the altimeters.
5. Connect the squibs to the top and bottom terminal blocks.
6. Tape the payload bay and squibs.
7. Prepare the drogue parachute.
8. Insert the electronics bay in the booster. Install the shear pins.
9. Prepare the main parachute.
10. Insert the main parachute bay over the electronics bay. Install the shear pins.
11. Install the motor.

Flight

1. Place the rocket on the pad.
2. Remove the arming pin.
3. Listen for audible confirmation of continuity for the ejection and cable cutter charges.
4. Make sure the launcher is in safe mode.
5. Twist the bare ends of the igniter together.
6. Insert and secure the igniter.
7. Attach the igniter clips, making sure they do not touch.
8. Test for continuity.
9. Check the tracking device.
10. Launch.

Chapter 9. Selecting Parachutes

Almost all high-power rockets are recovered using parachutes. You might see other forms of recovery on smaller, low-power rockets, like streamers, helicopter recovery, tumble recovery, or gliders, but these are rare on high-power rockets, primarily because high-power rockets are much heavier. Using a recovery method other than parachute recovery for a high-power rocket is not something we'll consider here.

There are three issues we need to deal with when selecting parachutes for our rockets. The first is calculating how fast the rocket should be traveling when it lands, and from that, how large the parachute needs to be. The second issue applies directly to dual deployment. While we want a rocket to fall as quickly as possible between apogee and the point where the main parachute deploys, there are limits. If the rocket is traveling too fast when the main parachute opens, the parachute can tear, or the rocket can be pulled apart. We need to have some idea of the maximum speed at which a rocket can be falling when the main parachute deploys. Finally, we must determine how big our rocket needs to be to hold a parachute of the right size. This is called the *packing size*, which is the amount of space we need to pack a shock cord and parachute.

There are two ways to approach these problems. People have been flying high-power rockets long enough to build up a good set of rules about descent speeds and packing sizes. That means we can use tables (included in this chapter) to determine reasonable parachute sizes and packing sizes. The second approach is to go through the math to figure out the basis for these rules. We'll do that, too.

If your goal is to select a parachute for your rocket quickly and get on with building and flying it, read the first part of this chapter, which presents rules of thumb and tables. If you want to understand the consequences of bending these rules a bit, read the entire chapter. It will give you a good start on understanding how your recovery system works.

General Rules for Recovery

The safe speed for opening a main parachute depends on a lot of things. You have to consider the mass of the rocket, since the energy at the moment the parachute opens goes up linearly with the mass of the rocket. You also need to take the strength of the recovery system into account. A parachute that opens slowly can open at a faster speed, since it slows the rocket a bit before the parachute snaps open. While we can get a handle on the speed using some basic math, and will do that later, in the end the only reliable way to know how quickly the rocket can be traveling to safely open the main parachute is to try it and see. A lot of people have done that over the years. In my own experience, I know, for example, that a 36” nylon parachute opening at 100 ft/s on a rocket the size of Callisto will tear, while a 48” parachute opening at about 50 ft/s works just fine on Deimos. Other experience seems to match my own. In the magazine *Peak of Flight*, issue 361, Tim Van Milligan recommends a maximum descent rate of 50 mph, which is about 73 ft/s. OpenRocket generates a warning if a parachute deploys at a speed faster than 20 m/s, which is about 66 ft/s. Based on these indices, and similar experience from a lot of other fliers, it seems reasonable to say that slowing your rocket down to about 50–75 ft/s is about right. Be sure your parachute and all other aspects of your recovery system are strong if you go for the high end of that range.

There are a lot of factors to consider for the maximum landing speed, too. We’ll get into that in detail in “Parachute Rocket Science”. Most sources recommend a landing speed of 15–20 ft/s. In fact, NAR recommends 20 ft/s as the maximum descent rate for a Level 3 rocket in its guidelines for Level 3 certification. In general, land the rocket as slowly as you can for a dual-deploy rocket. After all, the parachute doesn’t open until the rocket is pretty close to the ground, so you don’t pay much of a penalty for using a large parachute.

Table 9-1 shows the maximum allowed weight in ounces for several common parachute sizes. The desired descent speeds are shown in the column headers. The first two columns give a range of weights for landing a rocket with each parachute size, while the last two columns help you determine a good size for a drogue parachute.

As an example, let’s say I am flying Deimos on an AeroTech J350 motor using a cable cutter. According to my simulation, the rocket weighs about 69 ounces. That’s at liftoff, though. Checking the details in OpenRocket, I find that the propellant weight is around 13 ounces, so the parachute really only has to land around 56 ounces. Scanning down Table 9-1, I see that a 48” parachute will land a 45 oz rocket at 15 ft/s, and a 79 oz rocket at 20 ft/s. Deimos is in the middle of that range, so the 48” parachute should do nicely. Looking down one more row, I see that a 54” parachute will land the rocket at 15 ft/s. It’s perfectly reasonable for me to use either of those parachutes.

	15 ft/s	20 ft/s	50 ft/s	75
12”	3 oz	5 oz	31 oz	70
24”	11 oz	20 oz	124 oz	279
36”	25 oz	45 oz	279 oz	628
48”	45 oz	79 oz	496 oz	111
54”	56 oz	100 oz	628 oz	141
60”	70 oz	124 oz	775 oz	174

Table 9-1. Find the desired descent speed in the top row, and scan down until you fi close to the weight of your rocket, but not under the weight; read the appropriate p the leftmost column

The table makes a lot of assumptions, some of which may not be valid for your rocket. The assumptions are:

- The rocket is being flown at sea level. Don’t use the table if your launch altitude is over 2,000 feet above sea level.
- The coefficient of drag is 0.75. This is a good value for a typical flat nylon parachute, but is low for a more expensive hemispherical parachute.
- You are using a single parachute.

If any of these assumptions are wrong, read the chapter all the way through to find out how to deal with the issue you are facing.

Packing Size

There are two ways to look at packing parachutes and shock cords into your rocket. The first is at design time, when you want to know how much room to leave so you can eventually fit the parachute and shock cord into the rocket. The second is learning the techniques to safely pack a parachute and shock cord into the minimum amount of space. Let’s start with planning space for the shock cord and parachute when designing the rocket.

Most of the rockets in this book use 9/16” tubular nylon for shock cords. This stuff is strong, generally rated for 2,000 lb loads. It’s also cheap and stands up to recovery gases pretty well, although shock cord protectors are always a good idea to keep the worst effects of the ejection charge gases away from the shock cord.

In actual testing, a 20-foot-long shock cord that was simply wadded up and stuffed into a 3”-diameter tube took about 7” of linear space. A bit of math shows that this works out to 2.5 cubic inches per foot of shock cord. That’s a pretty good value to use for planning purposes. You can use a little less with some of the techniques we’ll discuss in a moment, and you may need a bit more if you go to a larger shock cord for some reason, but this is a good way to figure out the minimum space to allow for the shock cord.

Of course, you also need to know how long the shock cord will be. Basically, the longer, the better. Longer shock cords give the rocket parts time to slow down from air drag after the ejection charge pops the pieces apart, reducing strain on the rocket. East Coast fliers also like long shock cords because they make it more likely that part of the rocket will reach the ground, even if the parachute gets snagged in a tree! The general rule of thumb is to use a shock cord that is three to 5 times the length of the rocket. Deimos and Phobos are about five feet tall, give or take, so a 20-foot shock cord is in the right range.

The space needed for a parachute depends on a lot of factors, but in general, allow 1/6 to 1/4 the diameter of the parachute. For a 48” parachute, then, you should plan 8–12” into the length of the rocket for the parachute.

In real life, the space available may not work out in such an ideal way. Body tubes come in certain sizes. You may need to increase the size of the parachute because you’re flying a heavy motor or payload, or perhaps because you are flying at altitude. That’s when some packing tricks can come in handy.

Let’s start with the shock cord. While you can stuff a 20-foot-long shock cord into a 7” section of a 3” rocket like Deimos or Phobos, that’s really not the best way to pack a shock cord. The risk of tangling is minimal, but it goes up a bit when you just stuff the cord in. A wadded mess also takes up more room than a neatly folded shock cord.

Probably the most popular way to pack a shock cord is called *Z-folding* (see Figure 9-1). You fold the shock cord back and forth within a given space. Once folded, use weak rubber bands at the ends of the folds or a piece of painter’s tape around the middle to hold the bundle in place. Don’t remove the rubber bands or tape. The force of ejection is more than enough to pull the rubber bands or tape off, and they actually help the process. It takes a little force to dislodge the rubber bands or tape, which absorbs some of the energy from the ejection charge.

Z-folding reduces the volume needed from about 2.5 cubic inches per foot of shock cord to about 2.1 cubic inches per foot of shock cord. That reduces the length of the tube needed in Deimos or Phobos to pack a 20-foot shock cord from 7 linear inches to 6 linear inches.

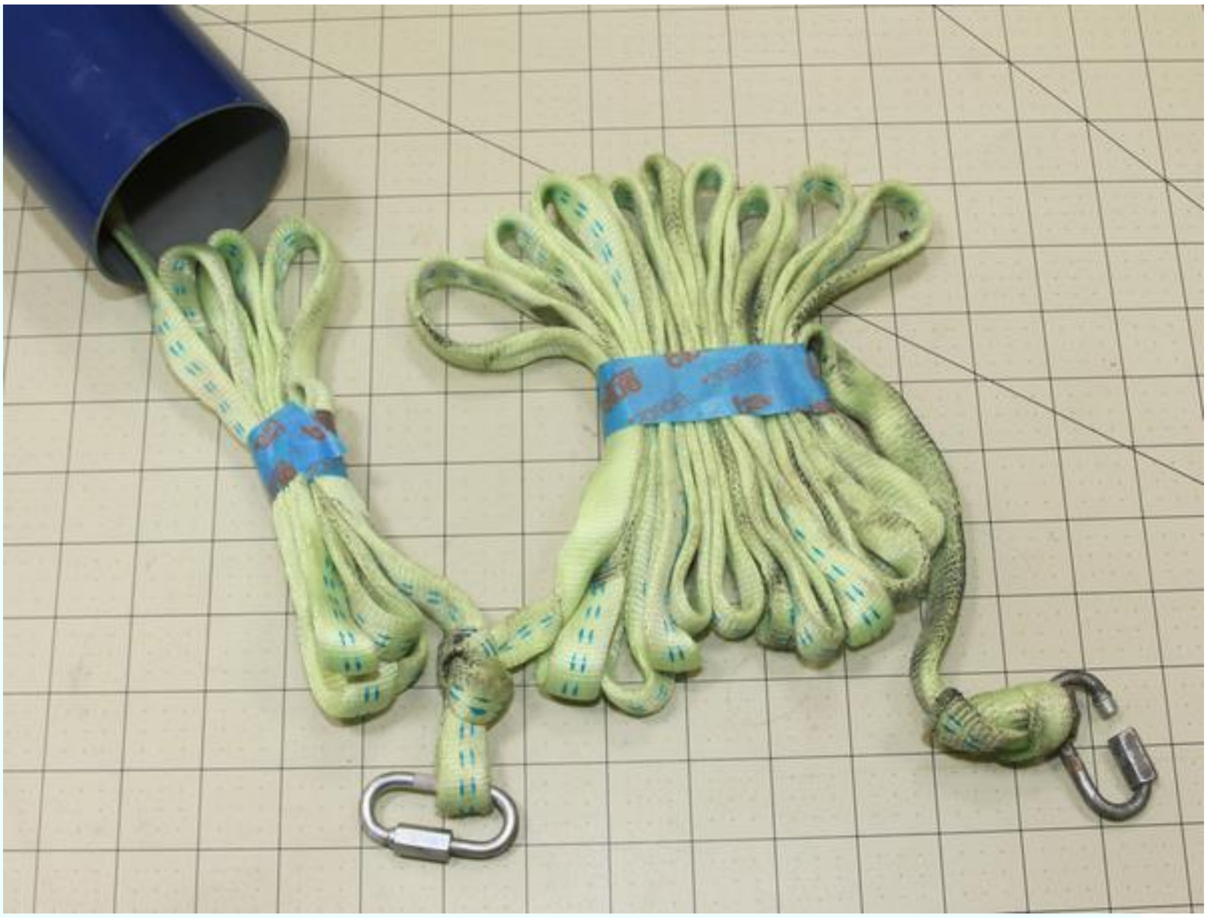


Figure 9-1. Z-folding is a common and effective way to pack a shock cord.

You’ve seen my personal favorite method for packing shock cords in the launch preparation sections of previous chapters. I like to roll the shock cord into flat pancakes, using tape to hold them together (see Figure 9-2). Just like with Z-folding, the tape helps reduce the energy from the ejection charge. Rolling also takes less space. I can pack a 20-foot shock cord into Deimos or Phobos using 5 linear inches of space. Overall, it takes about 1.8 cubic inches per foot of 9/16” tubular nylon. I also think rolling is the neatest of the three methods, and the least likely to snarl the shock cord, since each rolled bundle is independently stacked on top of the one that unfurls after it.

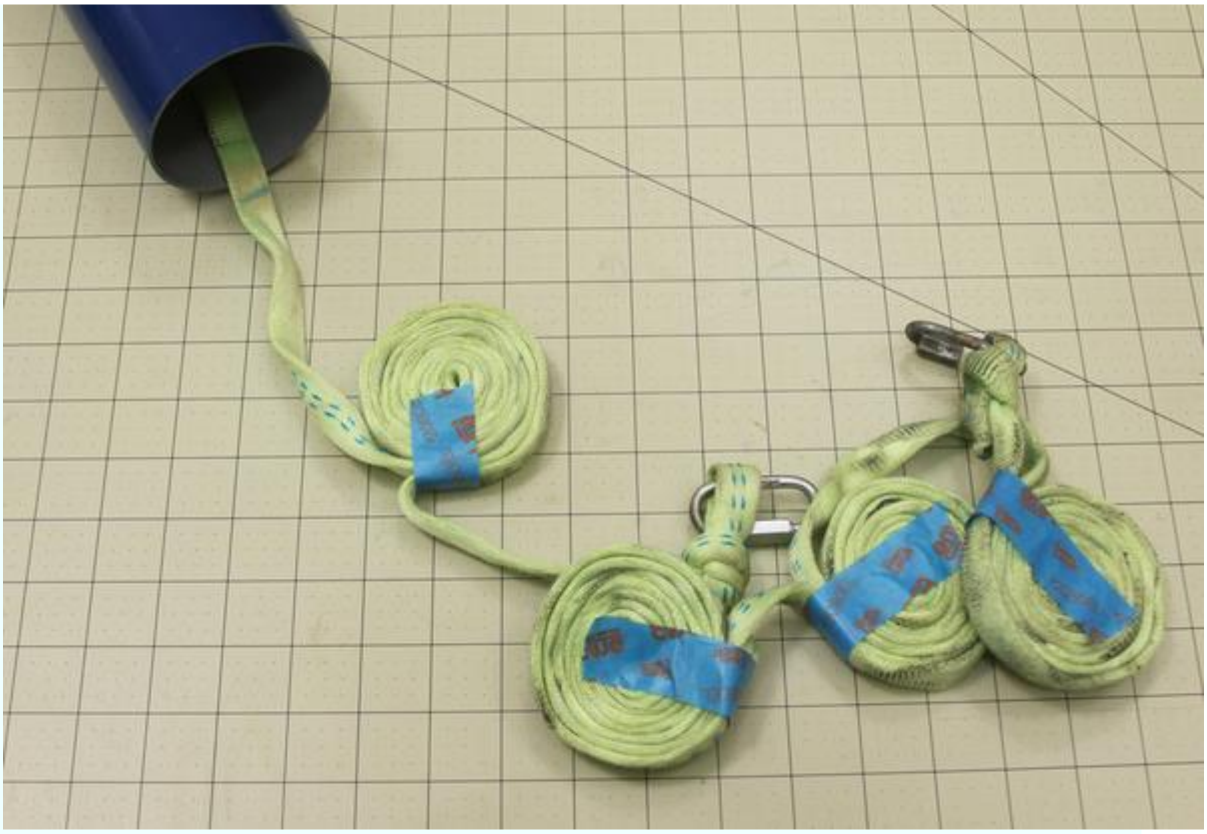


Figure 9-2. Rolling is a compact way to pack tubular nylon shock cord.

As you know from packing your Level 1 rocket, and perhaps from packing the Level 2 rocket, there comes a point when you fold the parachute lengthwise before wrapping it in a flame blanket. The number of times you fold the parachute is the controlling factor in how much space the parachute needs in the rocket body tube. You might think that the number of times you can fold the parachute would depend on its size, since you have to be able to stuff it into a fixed-size tube, and in an absolute sense that’s true. Large parachutes tend to be used in large rockets, though, and smaller parachutes are used in smaller rockets. Since the parachute size goes up and down with the size of the rocket, the number of times you fold it generally stays the same until you get to really big rockets. I’ve never seen a high-power rocket where the parachute could not be folded in half. That reduces the length of the parachute to 1/4 of its diameter, since the length before folding is the radius. In most cases, though, this is a fairly loose fit. You want the parachute to loosely fill the available volume so the parachute’s flame blanket provides some protection to the shock cord that is behind the parachute. Most of the time I end up folding the parachute in thirds, giving a length about 1/6 of the diameter of the parachute. It’s often possible to fold the parachute in fourths, but if you do that, be very sure the parachute can still slide in and out of the body tube easily. You do not want to have the parachute bind inside the body tube, failing to deploy because it is too tight in the tube.

The actual length needed to store the parachute in the tube is usually a bit shorter than 1/4 or 1/6 of the diameter of the parachute, because the spill hole doesn’t take up any room. The 54” parachute shown in Figure 9-3 uses about 12” of linear length when folded in half, and 8” when folded in thirds. I like the fit of the parachute better when it is folded in thirds.

WARNING

The rubber band shown in Figure 9-3 is there to hold the parachute in place for the photo. Do not use a rubber band around the parachute when you pack it. While weak rubber bands will easily snap off of a Z-folded shock cord, they *will* hold a parachute closed.

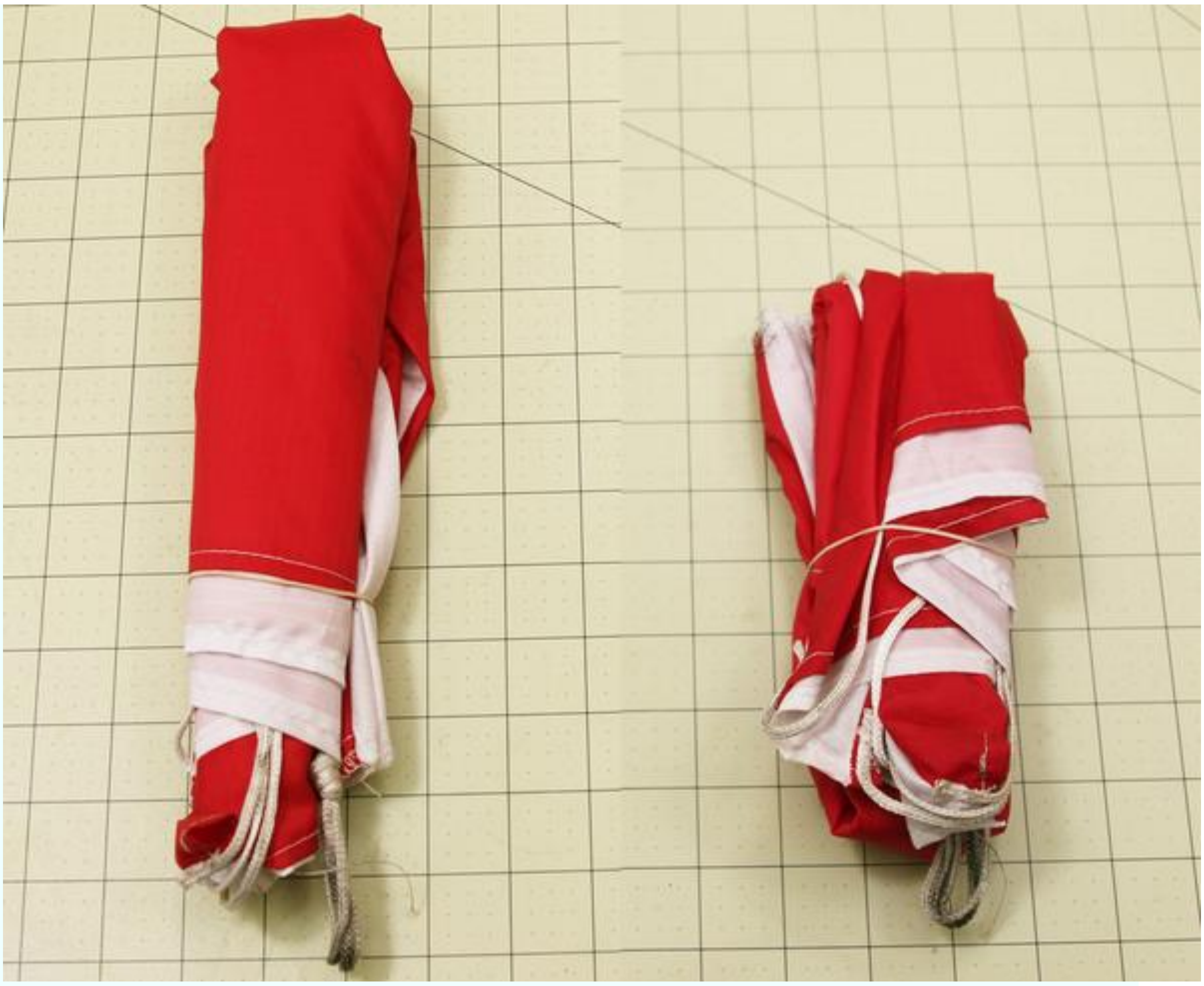


Figure 9-3. Once the parachute is folded into a long narrow tube, we fold it two, three, or four times to reduce the length needed for the parachute and to make a loose plug that will protect the shock cord from the ejection charge.

These are values you can figure out on your own by playing around with your shock cord and parachute. If you are planning a rocket before you have a closet full of parachutes and shock cord, though, you may need some advice on how much space to leave before you actually have the materials in hand. Take a look at the manufacturer’s website. Many will show the recommended packing sizes for their products. The values for some common PML parachutes, many of which you have seen folded in rockets in the book, are shown in Table 9-2, with shock cord packing sizes in Table 9-3.

Chute size>	PAR-18	PAR-24	PAR-30	PAR-36	PAR-48	PAR-54	PAR-60	PAR-72	PAR-84
Tube diameter									
2.1”	3.0	4.0	4.0	6.5	8.0	n/a	n/a	n/a	n/a
2.5”	2.0	3.5	3.0	5.0	6.5	9.0	n/a	n/a	n/a
3”	1.5	2.5	2.5	5.0	5.0	7.0	n/a	n/a	n/a
3.9”	1.0	2.0	1.5	3.0	4.0	4.0	5.5	12.0	14.0
6”	<1	1.0	<1	2.5	3.0	3.0	3.0	3.5	4.0
7.5”	<1	<1	<1	1.5	2.0	2.5	2.5	3.0	3.0
11.4”	<1	<1	<1	<1	1.5	1.5	1.5	2.0	2.0

Table 9-2. An abbreviated version of the table from PML’s website–PML also sells st
FORM parachute (created by Frank R. Uroda, Public Missiles Ltd.; used with

	3/8” (TN-0.375)	9/16” (TN-0.5625)	3/

Tube diameter			
2.1”	4.0	8.0	8.
2.5”	4.0	6.0	5.
3”	3.0	6.0	4.
3.9”	2.0	2.0	3.
6”	1.0	1.0	2.
7.5”	0.8	0.8	1.
11.4”	0.8	0.8	1.

Table 9-3. Shock cord packing lengths for 20 feet of tubular nylon from PML’s websit
R. Uroda, Public Missiles Ltd.; used with permission)

As you can see, for a 3” rocket like Deimos or Phobos, we should plan for around 17” of linear space for the shock cord and parachute, although we may need as little as 11”. These rockets have about that much space—a little more in some parachute bays, and a little less in others. Phobos, in particular, is a little short of space in the booster. There really isn’t enough space for a large parachute and a really large motor, like a CTI K1440W. On the other hand, you can pack the shock cord in the motor tube for shorter motors, and in the dual-deploy configuration, you can pack the larger parachute in the upper bay and the smaller drogue parachute in the booster section. I thought using the shorter, lighter, less expensive booster tube was a good design trade-off. You may disagree. If so, you can certainly lengthen the tube a bit when you build your version of the rocket.

Parachute Rocket Science

This section on parachute physics digs into two topics. The first is the energy of a falling body. It’s important to understand the ideas in this section if you want to step outside the narrow confines of using a table to select a parachute. You can’t make a reasonable choice about the acceptable descent rate of a rocket without understanding this topic. The second topic is the physics and math behind the tables from the first part of this chapter. You might want to read this section just for fun, but it also gives you the tools to really understand how to select the best possible parachute for a particular purpose.

If you’re content to use the tables for selecting a parachute, though, you can safely skip the rest of the chapter.

The Energy of a Falling Body

I’m going to make a clean break with the information you find on parachute selection in most books or articles by claiming that the recovery speed is not that important. The important factor when recovering a high-power rocket is the recovery *energy*. The whole point of using a recovery system is to avoid damage to people or property when the rocket lands, and that damage is caused by energy, not speed. If that seems preposterous, stop and think about this for a moment: air molecules traveling at about 505 meters per second are constantly bombarding you. Not only do they not hurt you, but if they slow down too much you get cold! A bowling ball dropped from a height of one meter is traveling over a hundred times slower, but I guarantee it will hurt more if it hits your foot. So again, it’s not the speed—at least not alone—that does the damage. It’s the energy.

Energy comes in many forms. The kind of energy associated with motion is called kinetic energy. The equation for kinetic energy is pretty simple. It is:

$$E = \frac{1}{2}mv^2$$

The reason this equation is important is because stopping a moving body requires energy, too, and the energy it takes to stop something is exactly the kinetic energy of the moving body. For a rocket falling from the sky, the energy to stop the rocket might be supplied by a small dent in the ground, a bump on a fin that bends it slightly, or any other sort of movement. In the end, most of this energy ends up as heat, but it’s not enough that you can measure the heat with instruments you are likely to have available.

The problem, though, is that the energy can also do damage to the rocket. It might chip some paint, break a fin, or crumple a body tube. It could damage things on the ground, too. This might be innocuous, like poking a hole in some dirt. If the rocket comes down with a lot of energy, though, it could do a lot of damage.

Let’s take a look at the equation for kinetic energy with this in mind. We can see that the energy goes up with the mass of the rocket. If one rocket weighs twice as much as another, and they are going the same speed, the rocket that weighs twice as much will have twice the kinetic energy. Since it is the energy we are worried about, this means we need a slower descent rate for heavier rockets.

The other factor in the equation is the velocity. This goes up as a square, though. If two rockets weigh the same, but one is moving twice as fast as the other, the faster object has four times the energy. This has impacts—sometimes literally—far outside rocketry. Think about automobile speed limits for a moment. Fifty-five miles per hour may seem insufferably slow on the highway. Let’s see what happens if we increase the speed to 78 miles per hour, though. The equation tells us that for the 55-mile-per-hour car, the kinetic energy is 3,025 multiplied by the mass of the car. At 78 miles per hour, the energy is 6,084 multiplied by the mass of the car. The energy has doubled, even though the speed only went from 55 to 78. That means the damage from a crash, both to the car and to the people in it, will be twice as bad at 78 miles per hour as it would be at 55.

Exactly the same thing happens with our rockets. As the speed goes up, the energy of the collision of the rocket with whatever it hits goes up even faster. Rockets are a lot smaller than cars, but they can go a lot faster, too. Several rockets in this book are capable of supersonic flight with larger motors. Ganymede, the Level 3 rocket shown in Chapter 13, travels at nearly 1,000 mph on a small M motor.

There are different units for kinetic energy, just like there are different units for speed and mass. While we can work in feet per second and ounces, most of the time people switch to the metric system when dealing with energy. Energy is measured in joules (J) in the metric system. In terms of kinetic energy, one joule is the energy of one half kilogram (about 1.1 pounds) moving at one meter per second (about 2.2 miles per hour). Table 9-4 shows the energy of Deimos in various configurations alongside some other moving objects.

Looking at Table 9-4 might seem a little scary, but keep in mind that two different objects with the same kinetic energy can do a very different amount of damage when they hit something. One reason is the shape of the object itself. A hard, pointed object like a dart is more likely to puncture something it hits than, say, a round object like a baseball. A rigid object like a baseball is more likely to do damage than an object that crumples. That’s definitely something to think about when picking materials for your rockets. Paper and plastic tubes will crumple in a high-speed impact, such as a *ballistic return*, where the parachute never pops out and the rocket careens in at terminal velocity. While Deimos will do significant damage if the parachute never opens, the fact that the body tube will shatter and crumple spreads the time of impact out significantly, which helps a lot in terms of reducing damage. Phobos is heavier, but even more telling, its fiberglass frame can survive impact with many objects. It can act like a giant dart, punching right through some materials. Not to put too fine a point on it, Deimos is a safer rocket to fly than Phobos.

Object	**Speed**	**Mass**
Nitrogen molecule in air	505 m/s	$4.6x10^{-26}$ kg
Deimos landing, 48” chute	5.06 m/s	1.59 kg
Bowling ball dropped from 1 meter	4.4 m/s	3.6 kg
90 mph baseball	40.2 m/s	0.145 kg
9 mm bullet	380 m/s	0.008 kg
100 lb boy riding a bike at 15 mph	6.7 m/s	45.4 kg
Pro football defensive back	8.0 m/s	90.3 kg
Deimos, ballistic return	102 m/s	1.59 kg

Object	**Speed**	**Mass**
Deimos at max speed, J350	262 m/s	1.59 kg
XTerra SUV, 55 mph	24.6 m/s	2,000 kg

Table 9-4. Kinetic energy of Deimos and miscellaneous moving obje

Parachute Aerodynamics

In general, we think of aerodynamics as a tool to let us decrease drag, allowing our rockets or airplanes to slip more easily through the air. The idea is just the opposite with a parachute—we want as much drag as we can get so we can slow the descent of our rocket.

The fundamental equation that governs drag is pretty simple. The force from drag is:

$$F_d = C_d \frac{\rho v^2}{2} A$$

where:

ρ

The density of air.

V

The velocity of the rocket.

A

The area of the parachute.

C_d

The coefficient of drag.

F_d

The force due to drag.

We actually want to find the velocity of the rocket, not the force of drag, so let’s rearrange the equation to:

$$V = \sqrt{\frac{2 F_d}{\rho A C_d}}$$

Once the parachute opens, the rocket will quickly reach terminal velocity—the point when the force of drag pushing up on the rocket exactly balances the force of gravity pulling down on the rocket (see Figure 9-4). That means we know the force of drag; it’s the same as the mass of the rocket in kilograms times the acceleration of gravity. It’s Newton’s second law of motion:

$$F = m a$$

You might know the mass of the rocket in grams or the weight of the rocket in ounces rather than the mass in kilograms, but it’s easy enough to convert. Divide by 1,000 to convert from grams to kilograms. Multiply by 0.02835 to convert from ounces to kilograms. Technically, converting from ounces to kilograms also converts from force to mass, which are two entirely different things, but it works with the assumption that the rocket was weighed on the surface of the Earth. The acceleration of gravity is 9.8 meters per second squared.

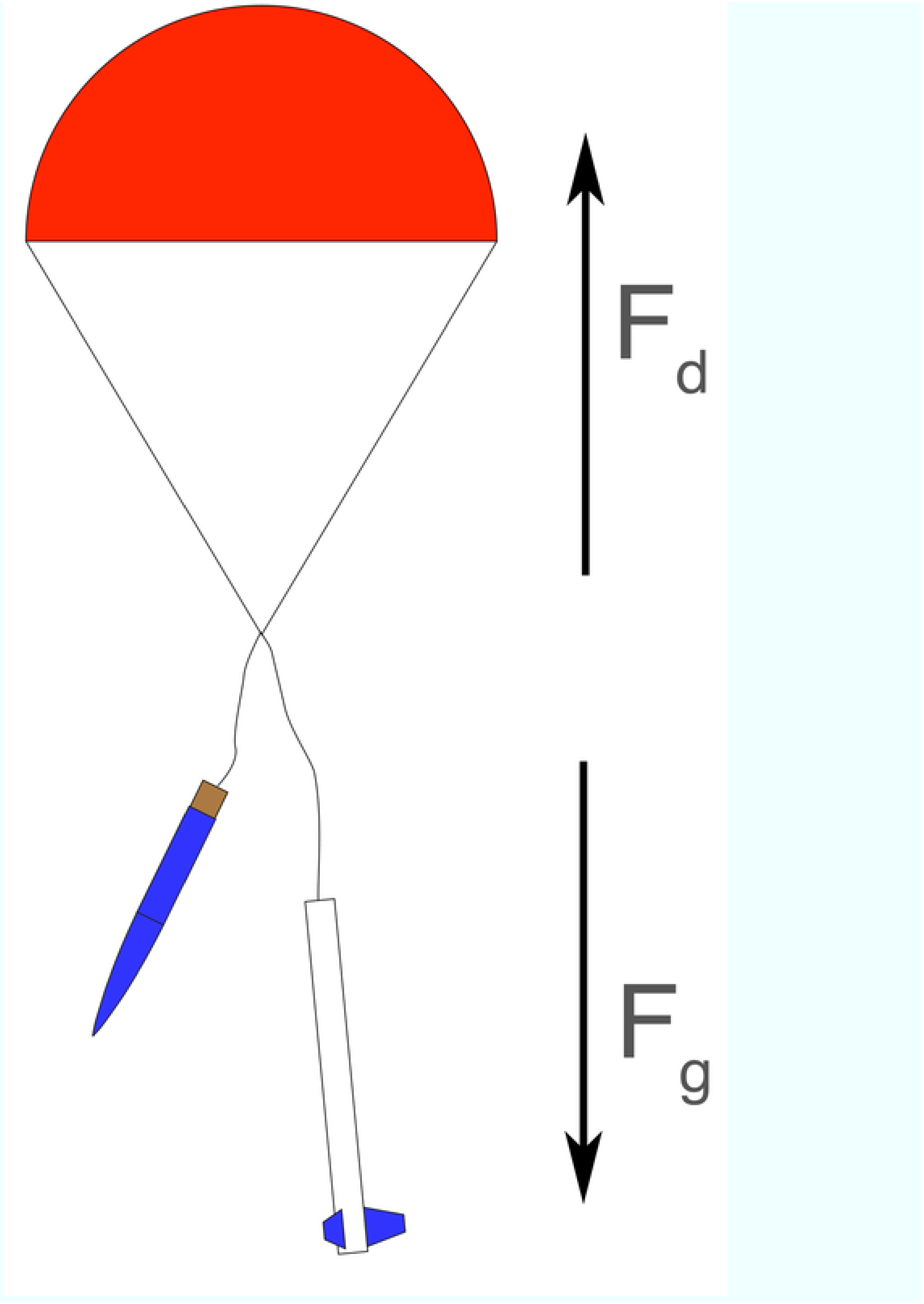


Figure 9-4. At terminal velocity, the force from gravity pulling the rocket down is exactly balanced by the force of drag.

Once all of the fuel is expended, Deimos coming down from a flight on an AeroTech J350 motor has a mass of about 1.59 kg. The force on the rocket, then, is 15.58 newtons, and at terminal velocity, that’s also the force of drag.

The density of air is about 1.22 kilograms per cubic meter. This is at sea level, and altitude does play an important part in reducing the density of the air (see Figure 9-6). Here in Albuquerque, our altitude is such that the air density is about 1.06 kilograms per cubic meter, so I generally go up one parachute size from the size shown in Table 9-1.

However…

You can get as precise as you like with the terms for calculating density of air, adding in the effects of temperature and humidity if you like, but the error in our other terms is likely to be large enough to swamp any reasonable approximation you make here. All of the tables from the first part of the chapter were calculated with an air density of 1.22 kilograms per cubic meter.

The area is the area of the parachute. Parachutes come in a variety of shapes. For a standard flat hexagonal six-string parachute, the area of the parachute is:

$$A = \frac{d^2 \sqrt{3}}{2}$$

where *d* is the distance across the parachute, as shown in Figure 9-5. Octagonal parachutes are also common on high-power model rockets. For an octagonal parachute, the area is:

$$A = \frac{2\,d^2}{\sqrt{2} + 1}$$

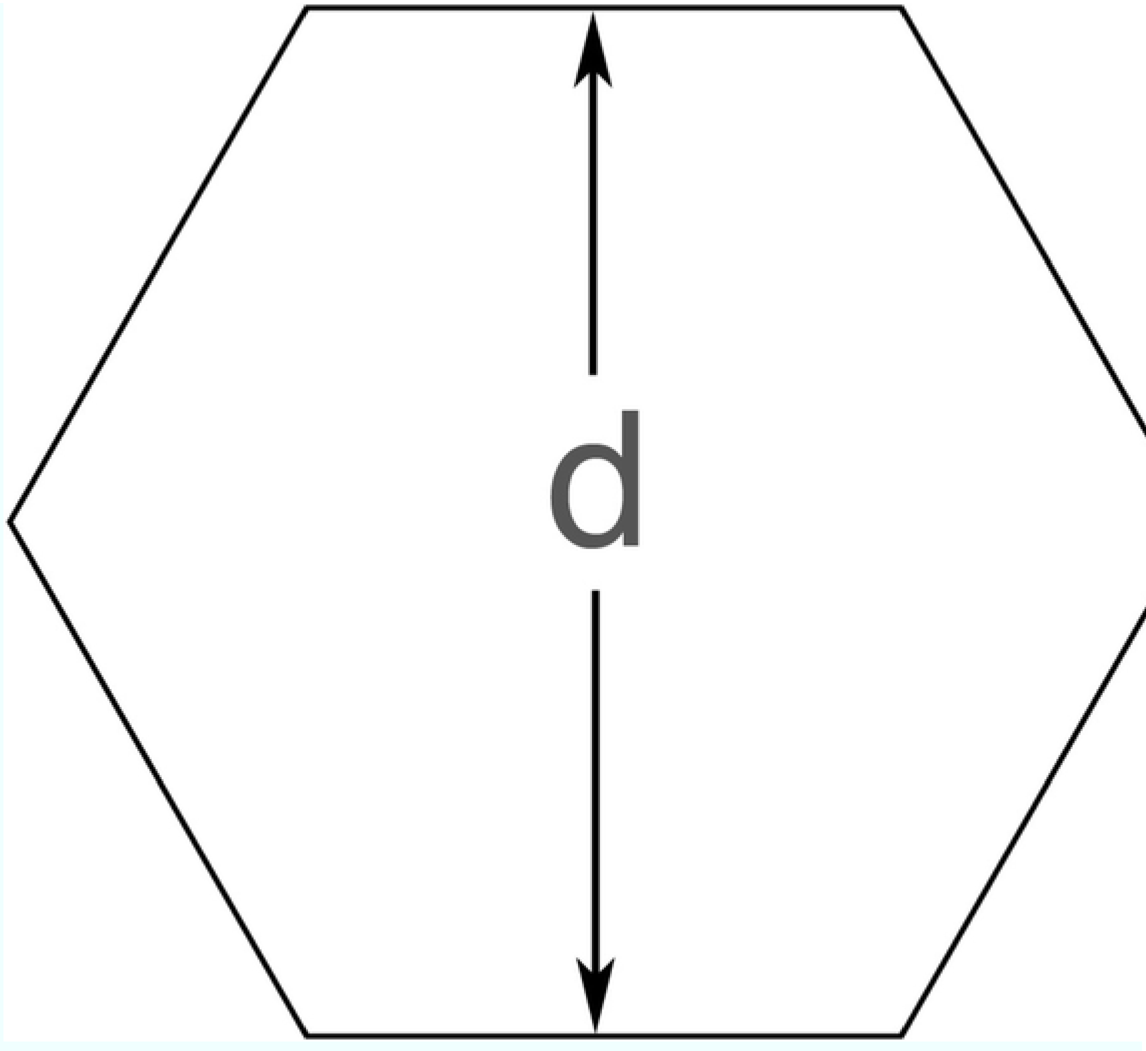


Figure 9-5. The distance across the parachute is measured from one side to the other, not from one corner to the other.

Large commercial parachutes almost always have a hole in the center, which decreases the oscillation of the parachute during descent. Subtract the area of the hole from the overall area of the parachute.

Remember to convert the size of the parachute from inches to meters, since all of the other values used in this section are in the metric system. Table 9-5 shows common parachute sizes in inches and meters, and the area in square meters.

Inches	Meters	Area (6 sides)	Area (8 sides
12	0.305	0.080	0.077

Inches	Meters	Area (6 sides)	Area (8 sides
24	0.610	0.322	0.308
36	0.914	0.724	0.693
48	1.219	1.287	1.231
54	1.372	1.629	1.559
60	1.524	2.011	1.924

Table 9-5. Common hexagonal and octagonal parachute sizes in inches and meter square meters

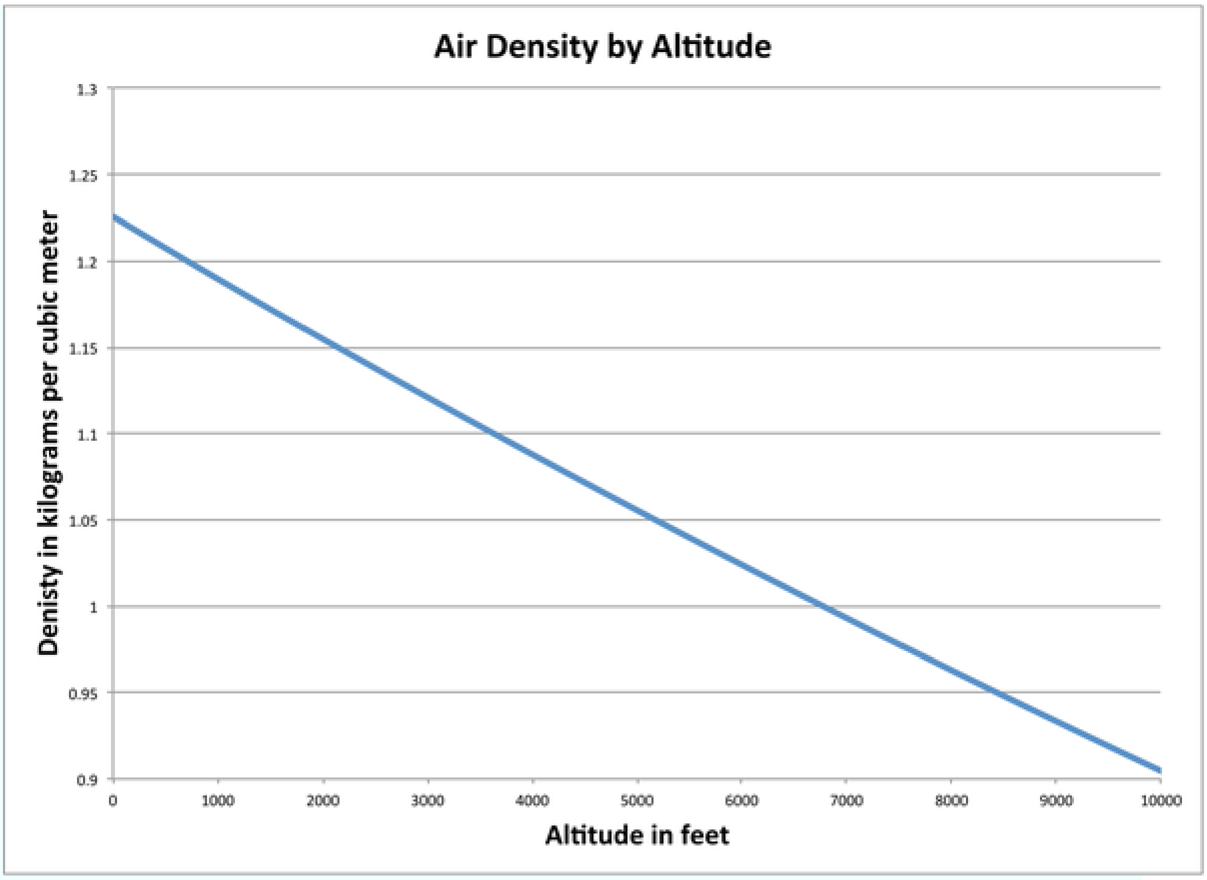


Figure 9-6. Air density varies with altitude, temperature, and humidity. This plot shows the effect of altitude.

The last term is the coefficient of drag. The generally accepted value for the coefficient of drag for a flat parachute is 0.75. This is something that can vary a lot, though. While inexpensive flat parachutes like the ones shown in this book have a coefficient of drag around 0.75, larger parachutes are often made with better shapes. An elliptical parachute, for example, has a coefficient of drag around 1.5. They are more expensive, but since the drag coefficient is twice that of a flat parachute, you can use a parachute half the size of a flat parachute, too. Fruity Chutes sells another parachute called the Iris Ultra (shown in Figure 9-7), which has a coefficient of drag around 2.2. Again, you pay more, but the advantages of using a smaller parachute that packs into a smaller space may be worth the price.

Parachute Spill Holes

Take a close look at the parachutes the next time you are flying rockets with a large group of people. The chances are pretty good that the larger nylon parachutes have a hole in the middle. You might even see holes cut in some of the small plastic parachutes used on small model rockets. Why would anyone cut a hole in a parachute?

The answer, amazingly enough, is that it makes the parachute more stable.

The round canopy of a parachute traps some air underneath it as the rocket descends. The slightest imbalance causes air to spill out of the side of the parachute that is highest up. That causes the parachute to move to the side, raising that side even more. The parachute continues to move to the side until it swings so far that the rocket swings it back like a pendulum, and the parachute swings back the other way. The parachute continues to rock back and forth, or perhaps to twist if it isn’t perfectly round. Cutting a hole in the middle of the parachute lets some of the excess air escape from the center of the parachute, reducing the rocking motion and stabilizing the load.

You might think the hole would make the parachute less efficient. It does, but not nearly as much as you may expect. Cutting a 6” spill hole in the middle of a 48” round parachute only reduces the total area of the parachute by 4%. The descent rate goes up even less. According to a RockSim calculation, putting a 6” hole in the 48” parachute used with Deimos only increases the descent rate by 0.9%, a small enough difference that you can ignore it for the purpose of picking a parachute.

Another odd fact is that the spill hole can actually *reduce* the descent rate! That’s because all of that oscillation spills a lot of air. If the oscillation without a spill hole is big enough to reduce the efficiency of the parachute by a lot more than 0.9%, adding a spill hole with a diameter 12.5% that of the parachute will bring the rocket down more gently.

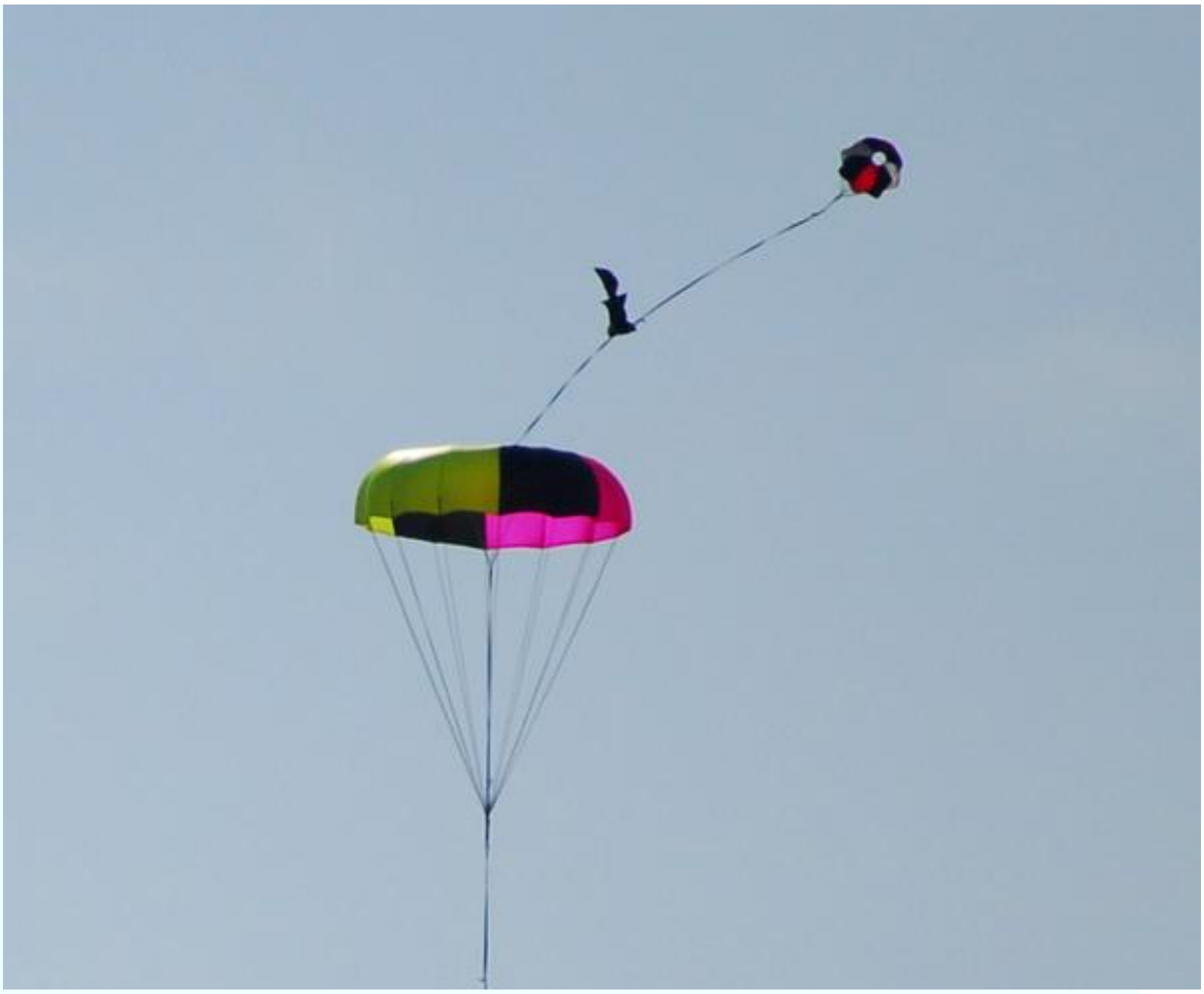


Figure 9-7. Shape does matter. While an inexpensive flat parachute has a coefficient of drag of about 0.75, this Iris Ultra from Fruity Chutes has a drag coefficient of 2.2, making it three times as efficient for the same size parachute. Photo by Fruity Chutes, used with permission.

EXAMPLE: FIND THE SPEED OF DESCENT FOR A ROCKET

Let’s see how we can put all of this information to use.

Let’s say we’re getting ready for a trip to BALLS in Black Rock, Nevada, to fly the dual-deploy version of Phobos on a CTI K1440W motor. The OpenRocket simulation says this beast will propel Phobos at a speed of 1,528 ft/s, or about Mach 1.4. Is our normal 54” parachute big enough for this flight?

The equation for speed is:

$$V = \sqrt{\frac{2F_d}{\rho A C_d}}$$

We need the mass of the rocket to find the force at terminal velocity. From an OpenRocket simulation, we find that the liftoff weight of the rocket is 175 oz, and the propellant weight for the CTI K1440W is 41 oz. This gives a recovery weight of 134 oz, or 3.8 kg.

The density of air is less at Black Rock than at sea level. Checking the internet, we find that Black Rock is about 4,000 feet above sea level. Checking Figure 9-6, we find that the air density at this altitude is about 1.08 kg/m^3.

An eight-sided 54” nylon parachute has an area of 1.559 m^2, but mine also has an 8” spill hole. Remembering to convert inches to meters and use the radius of the spill hole rather than the diameter, the area of the spill hole is:

$$A = \pi r^2$$
$$A = \pi \times 1.016^2$$
$$A = 0.032\,\mathrm{m}^2$$

This gives an area for the parachute of 1.527 m^2.

We’ll use the standard coefficient of drag for a flat parachute of 0.75.

Putting all of this together, the descent rate for Phobos will be:

$$V = \sqrt{\frac{2\,F_d}{\rho\,A\,C_d}}$$

$$V = \sqrt{\frac{2 \times 3.8 \times 9.8}{1.08 \times 1.527 \times 0.75}}$$

$$V = 7.6\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$V = 25\,\frac{\mathrm{ft}}{\mathrm{s}}$$

This is faster than our typical upper-end descent rate of 20 ft/s. Since the impact from energy goes up as the square of velocity, going from 20 ft/s to 25 ft/s increases the energy of impact by 56%, which is quite a lot. On the other hand, Phobos is a fiberglass rocket that can take that kind of impact, and we’re flying at Black Rock, a dry lake bed with nothing but fine sand for miles in any direction. The only other people who will be at BALLS are people flying high-power rockets. It’s a judgment call. Some people might choose to use the 54” parachute, especially since they will have a drogue parachute to help slow the descent a bit. I can see that argument, but personally, I would pack my 60” hemispherical parachute. With the larger area and a drag coefficient around 1.5, this parachute will bring the rocket down with a much slower speed:

$$V = \sqrt{\frac{2\,F_d}{\rho\,A\,C_d}}$$

$$V = \sqrt{\frac{2 \times 3.8 \times 9.8}{1.08 \times 2.74 \times 1.5}}$$

$$V = 4.1\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$V = 13\,\frac{\mathrm{ft}}{\mathrm{s}}$$

That’s a much nicer descent rate, and I’m really not worried about the rocket drifting too far with a dual-deploy recovery system and miles of flat sand for the recovery area.

EXAMPLE: HOW MUCH DOES THE DROGUE PARACHUTE HELP?

Rockets like Deimos and Phobos are often flown using dual deployment with two parachutes. How much does the other parachute help with reducing the descent rate?

To find out, let’s take a typical example of Deimos flying on an AeroTech J350W motor. We’ll plan for a 48” main parachute and an 18” drogue. Let’s start by making sure the drogue parachute will slow the rocket down to a safe speed for the main parachute to open.

Working with the OpenRocket simulation, we find that the recovery weight for the dual-deploy configuration of Deimos is 83.9 oz, or a mass of 2.38 kg. We’ll use a density of 1.22 kg/m^3 for a sea-level launch. A typical 18” parachute has six strings, so the area is 0.18 m^2.

The coefficient of drag is 0.75. Putting all of this together, the descent speed with the drogue parachute is:

$$V = \sqrt{\frac{2\,F_d}{\rho\,A\,C_d}}$$

$$V = \sqrt{\frac{2 \times 2.38 \times 9.8}{1.22 \times 0.18 \times 0.75}}$$

$$V = 16.8\,\frac{\text{ft}}{\text{s}}$$

$$V = 55\,\frac{\text{ft}}{\text{s}}$$

That’s in the right range. Actually, a 12” drogue works, too, since the rocket flopping around adds a fair amount of drag, but we’ll ignore that for now.

Adding the effect of the 48” main parachute is easy enough. We just need to increase the area of the parachute. With a 6” spill hole and eight shroud lines, the 48” parachute has an area of 1.22 m^2, for a total area of 1.4 m^2. The descent rate with just the 48” parachute is:

$$V = \sqrt{\frac{2\,F_d}{\rho\,A\,C_d}}$$

$$V = \sqrt{\frac{2 \times 2.38 \times 9.8}{1.22 \times 1.22 \times 0.75}}$$

$$V = 6.5\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$V = 21.2\,\frac{\mathrm{ft}}{\mathrm{s}}$$

That’s close enough to 20 ft/s to feel like the 48” parachute is a good choice. Adding in the drogue, we expect a descent rate of:

$$V = \sqrt{\frac{2\,F_d}{\rho\,A\,C_d}}$$

$$V = \sqrt{\frac{2 \times 2.38 \times 9.8}{1.22 \times 1.4 \times 0.75}}$$

$$V = 6.0\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$V = 19.8\,\frac{\mathrm{ft}}{\mathrm{s}}$$

The drogue doesn’t make a significant impact, but it does help somehat.

Chapter 10. Tracking Your Rocket

Deimos and Phobos are perfectly capable of flying well out of sight, and even Callisto can be difficult to see. You might watch the entire flight, only to lose the rocket in the middle of a farm field or stand of grass. There are many times when I've been within a few feet of a rocket before I could see it, and that's in the high mountain deserts of New Mexico. When you consider that the rocket can easily land a half-mile away, sometimes even more, it's easy to see why losing a rocket is a very big concern. Even if you don't lose the rocket, you may not want to spend an hour or more walking around trying to find it.

Also, keep in mind that all of your certification flights require that you locate the rocket and return it for inspection. If you lose the rocket, you will have to repeat the certification flight.

There are currently four practical ways to track and recover a rocket. You can use line of sight, preferably from two or three widely separated observers so you can triangulate on the landing location. This is the method most often used in low-power rocketry, and it's still used on smaller high-power rockets. You can use sonic devices, like an electronic beeper or siren, to zero in on the rocket by sound. There are also several devices to track rockets with directional radio signals. Finally, there is the occasionally temperamental gold standard of rocket location, global positioning satellite (GPS) beacons. This chapter takes a look at the last three methods.

Sonic Devices

You might be tempted to skip right over this section. Using a sound generation device to find a rocket seems so primitive! In truth, it's rarely the only method we use to find a high-power rocket, but it is a lot more useful than it first appears.

Sonic tracking is generally used to augment the other recovery methods, not as the sole method for recovering a rocket. Line-of-sight tracking rarely gets you right up to the location of the rocket. You are almost always walking in a line toward where the rocket was last seen, generally with only a vague idea how far away the rocket landed. A beeper or siren, blaring away from your rocket, lets you know when you are getting close. You might expect that with a radio or GPS you would get pretty close to the rocket, and by and large that is correct. Still, there are a few times when I’ve been very close to the rocket a still had trouble seeing it. Recovery gets even harder if you live in an area where the rocket can land in ditches or fields of tall plants. Unless the parachute conveniently drapes over the top of a plant, you could be standing one or two rows of corn from your rocket and not know it was there. GPS or a directional radio will get you close, but if they are backed up by a sonic device, the last part of the search can be a lot faster.

The other advantage of sonic devices is that they are inexpensive. Radio or GPS trackers will each cost several hundred dollars, but you can build or buy a sonic tracker for a few dollars to a few tens of dollars. The sonic tracker in Figure 10-1, available from Pratt Hobbies, is a great example. It’s small and light enough to use in most low-power rockets. It can slide into a low-power BT-20 body tube. It works well with high-power rockets, too, fastening to a quick link or screw eye with the integrated Tyvek thread. Once the battery is inserted, the Microbeacon emits an annoying high-pitched warbling sound that makes it easy to find. The LED is an interesting addition, although it may be more useful for a night flight of a low-power rocket than for high-power rocketry. While the battery seems unlikely to fall out, I think it’s always a good idea to secure it firmly with a rubber band, zip tie, or tape.

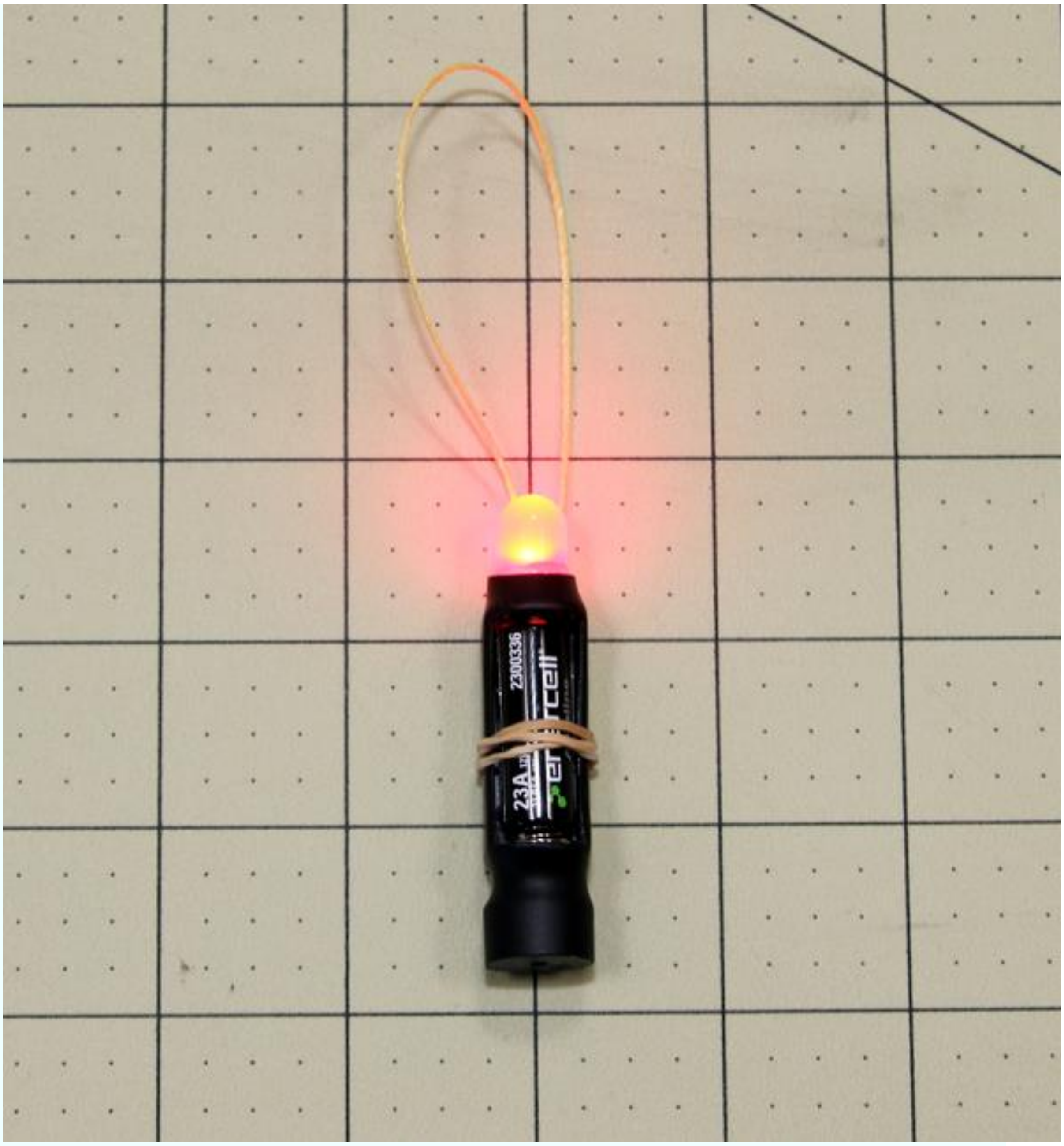


Figure 10-1. The Microbeacon from Pratt Hobbies.

While it’s hard to beat a commercial tracker like the Microbeacon for cost, it can be a fun project to build your own. Figure 10-2 shows a breadboard version of a sonic tracker. This one even includes a photocell that turns the sound off when the photocell is in the dark. If you build the photocell, and perhaps the buzzer, into the bulkhead of your rocket, you don’t have to listen to it buzz while waiting for the launch. Once the ejection system deploys, the photocell will be in the light, and the buzzer will start sounding off.

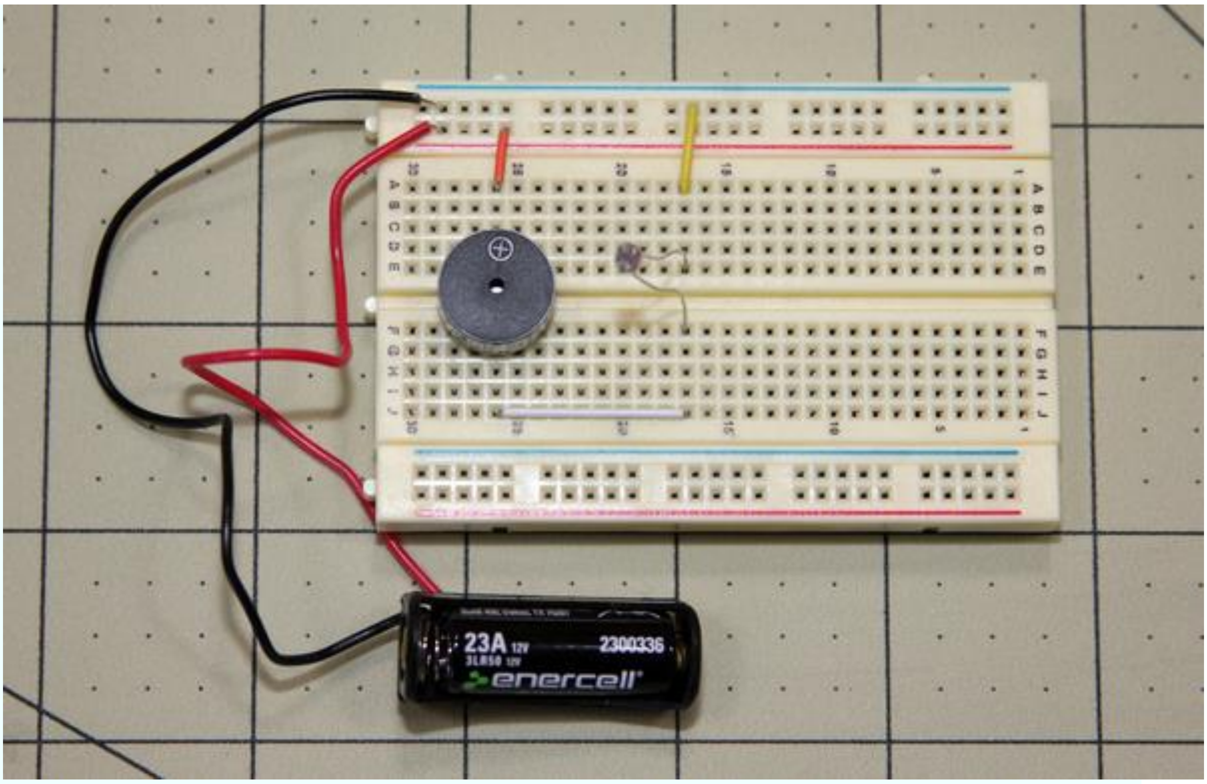


Figure 10-2. Simple sonic beacons are easy to build.

Table 10-1 has the parts list, excluding connection wire and the breadboard, which you probably have in your parts box if you are an electronics tinkerer. The part numbers are RadioShack catalog numbers.

Part	**Description**
12VDC Piezo Mini Buzzer	70 dB electric buzzer
Cadmium-Sulfide Photocell	Light sensor
N Battery Holder	Battery holder
N Battery	12V battery

Table 10-1. Parts list

Wiring is pretty simple. Just wire the battery, buzzer, and photocell in series. The buzzer has a small + sign over one terminal; make sure it points toward the positive terminal on the battery.

Directional Radios

Line-of-sight tracking and sonic tracking both fail when a rocket goes out of sight. Sure, you sometimes pick up sight of a rocket again as it descends, but sometimes you don’t. That’s when a directional radio or GPS tracker becomes essential.

Directional radios have been around for a long time. Many of the ones used in rocketry were originally developed for an even more demanding hobby: falconry. The radio transmitters had to be small enough and light enough that they could be attached to the leg of a bird without unduly hampering its flight, yet they needed to be able to track the bird over long distances. That makes them ideal for rocketry.

The basic components of a radio tracking system are a radio transmitter, a radio receiver, and a directional antenna. You can buy these systems, like the one seen in Figures 10-3 and 10-4, or if you are adventurous in electronics, you can build some or all of the components yourself. It’s tough to build a radio transmitter or receiver for the price you would pay for a commercial one, but I’ve seen a few home-brewed directional antennas.

Mounting the transmitter is pretty easy. In fact, you have seen falcon transmitters mounted in the payload bays for both Deimos and Phobos. If you turn back to Chapter 8, you’ll notice that Figure 8-17 shows the transmitter from Figure 10-3 mounted on the sled for Deimos. It’s worth noting that the antenna for the transmitter is curled around instead of stretched out straight. It’s better to leave the antenna straight, but it will still work almost as well with the bend, and takes up a lot less room. Don’t cut the antenna, though! The length is actually a lot more important than how straight it is.

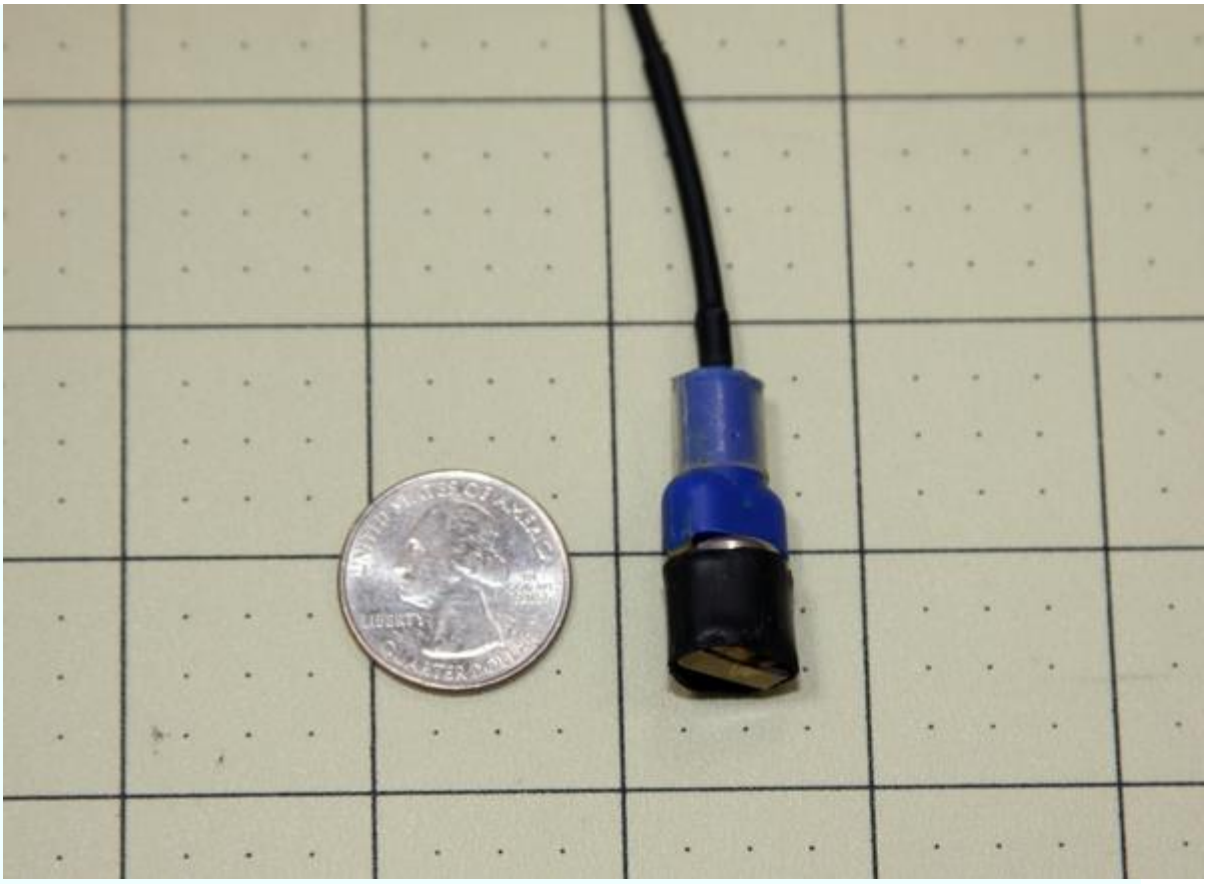


Figure 10-3. A transmitter designed for falconry.

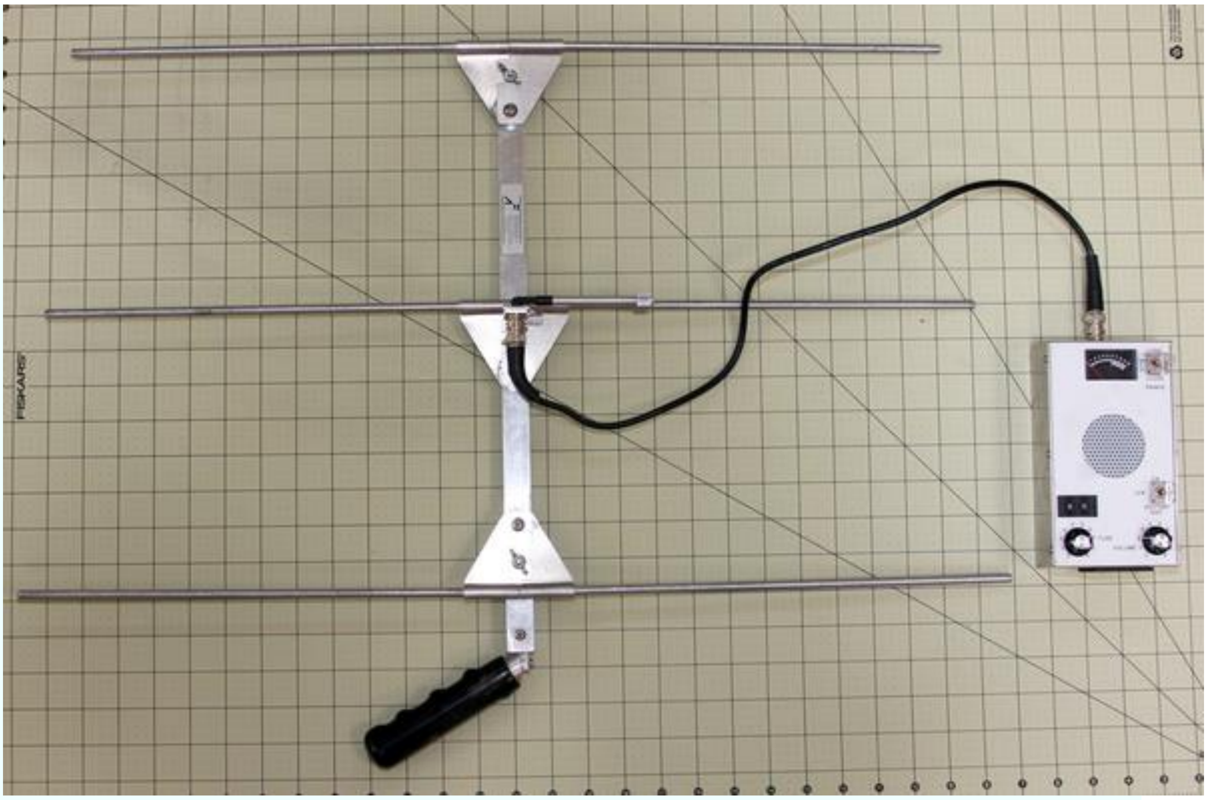


Figure 10-4. A typical tracker consists of a radio receiver and a directional antenna.

Using a directional antenna like the one shown in Figure 10-5 is pretty easy. Once the transmitter and receiver are turned on, and the receiver is set to the frequency of the transmitter, you will hear a regular beep. Stand a few yards away and sweep the antenna slowly back and forth. The beep will be significantly louder when the antenna is pointed at the transmitter. Choose an object in the direction of the loudest beeping and walk to it, checking periodically and correcting your direction. While you don’t need any practice to use a system like this successfully, after using it a couple of times you will be able to tell about how far away you are with reasonable accuracy, too.

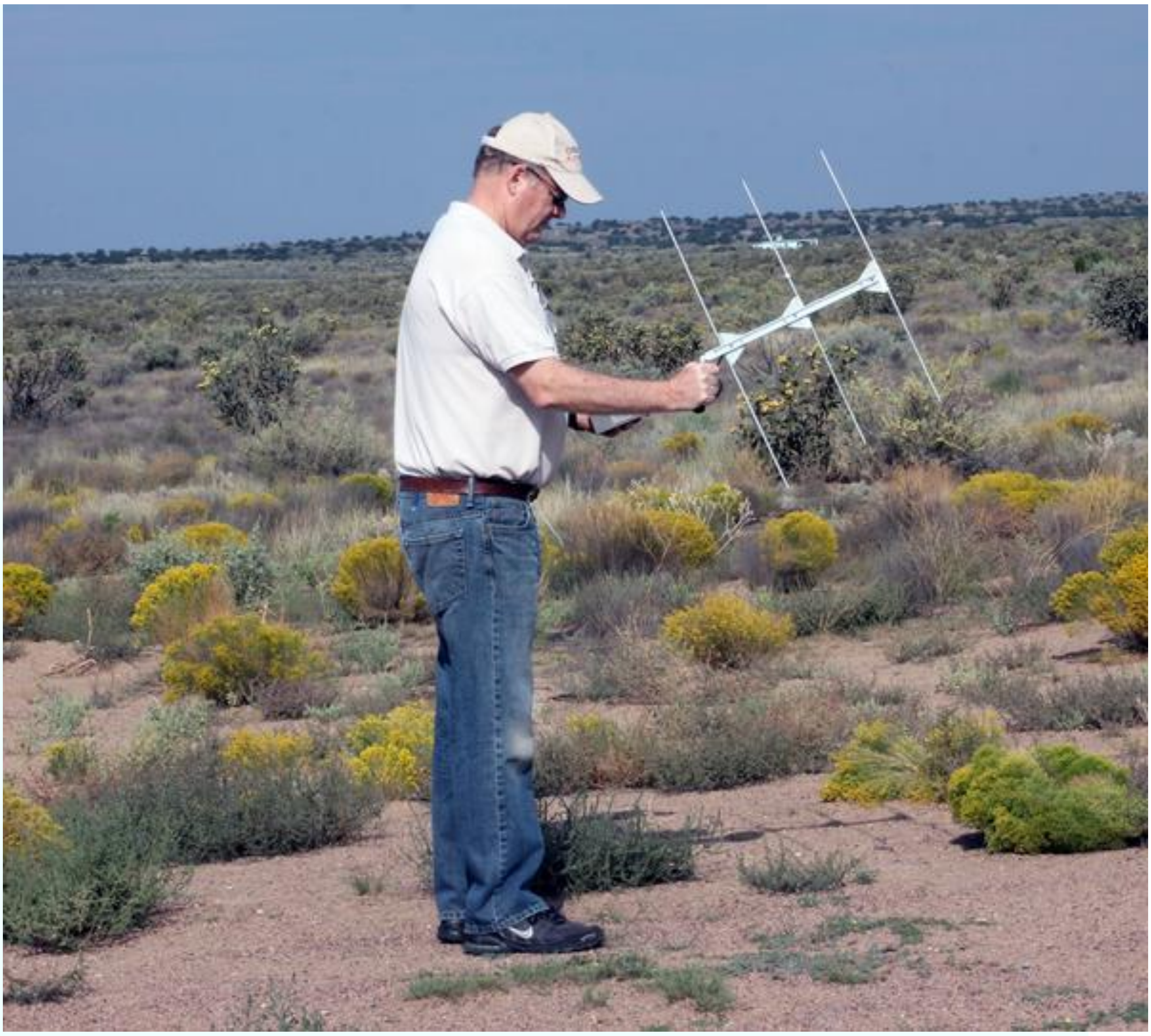


Figure 10-5. The author tracking down a rocket.

GPS

While you are likely to see several people using radio trackers at a rocket launch, GPS trackers are becoming more common. There are lots of different options available for tracking rockets with GPS. We'll look at one here that is pretty representative of what is available.

What You Need

The popular TeleMega 2 from Altus Metrum is one of several variations on the same basic theme. Altus Metrum also sells bare GPS transmitters and other altimeters. The TeleMega 2 is a high-end flight computer, similar to the Missile Works RRC3 described in "Choosing an Altimeter". The big difference is the addition of a GPS device and a radio transmitter. Table 10-2 shows the parts needed to get started with the TeleMega. Figure 10-6 shows the flight computer itself.

Part	Description
TeleMega v2.0	Flight computer and GPS transmitter.
Altus Metrum Starter Pack	Includes the TeleDongle radio receiver, a LiPo battery for the cable to connect it to a laptop computer.
Arrow Model 440-3	Antenna for the TeleDongle. There are good alternatives; see
SMA-BNC Adapter	A male-to-male adapter, used to connect the Arrow antenna t

Table 10-2. Parts list

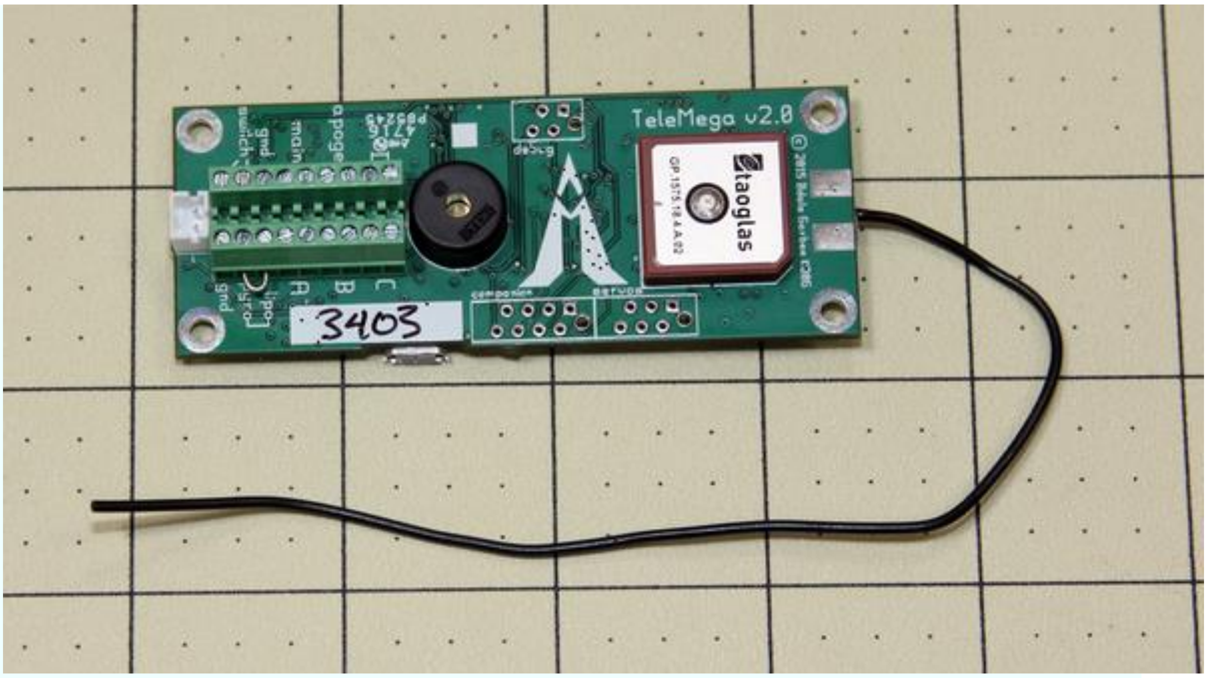


Figure 10-6. The TeleMega 2 from Altus Metrum is an altimeter plus a GPS transmitter.

There are several pieces you need besides the TeleMega 2. The first is a receiver called the TeleDongle 3. This is the radio receiver that picks up the signal transmitted by the TeleMega 2. One end attaches to a laptop computer through a USB port, while the other attaches to an antenna using an SMA connector. The antenna is expected to have a male SMA connection, while the TeleDongle has a female connection.

The TeleDongle is available separately, or you can get it in a package called the Altus Metrum Starter Pack. The starter pack also includes a USB A to micro-B cable, used to download flight information from the TeleMega after the flight, and an 850 mAh LiPo battery. The battery can dump a large amount of current into an igniter, so it’s ideal for setting off ejection charges or even for staging. If you’ve used LiPo batteries, you know that charging them requires a special charger. You won’t need the charger, though. The TeleMega itself will charge the battery if it is plugged into a USB power source using the supplied cable. The starter pack is shown in Figure 10-7.

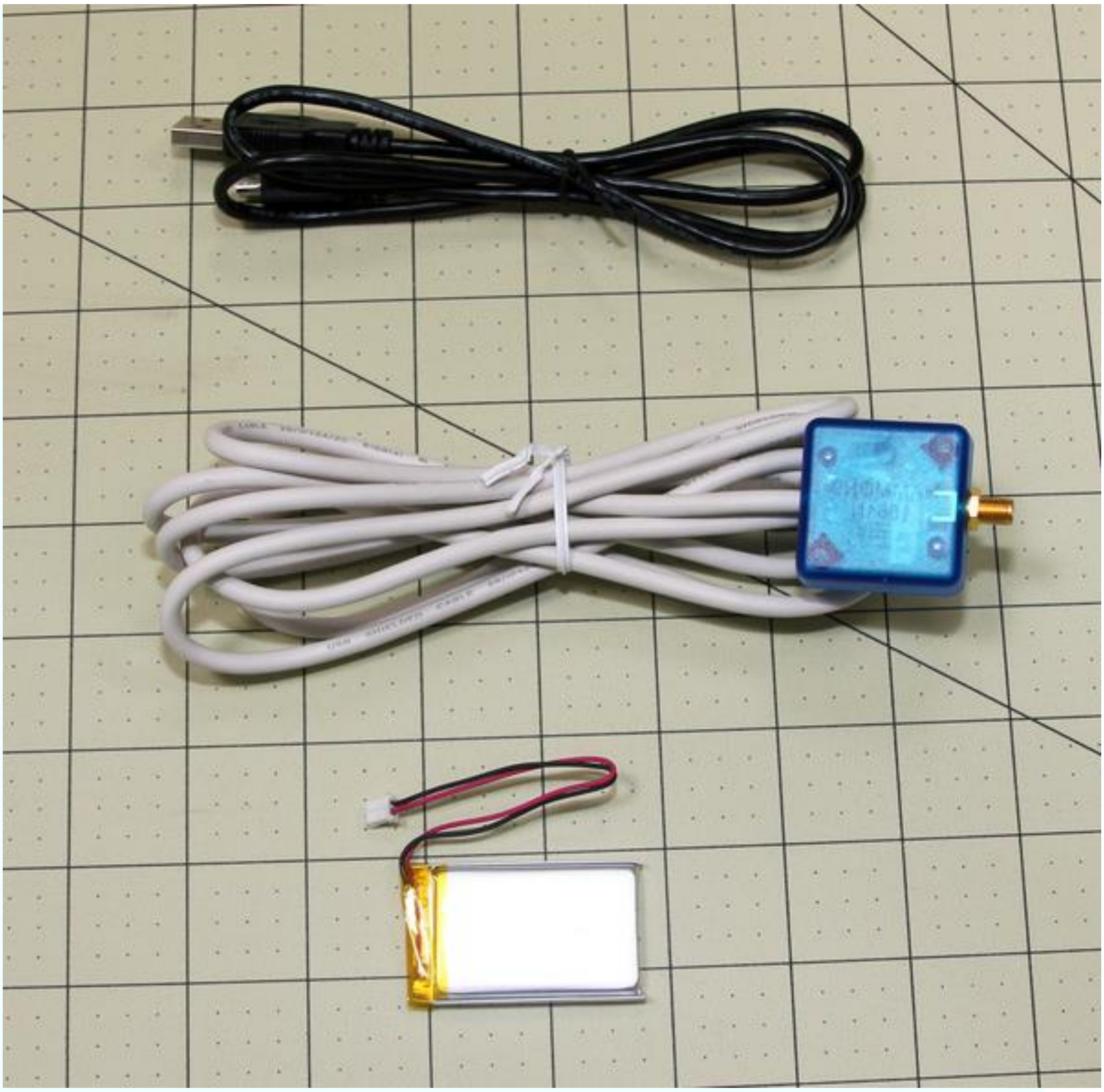


Figure 10-7. The Altus Metrum Starter Pack includes, from top to bottom, a cable to connect the TeleMega to a computer, the TeleDongle receiver, and a LiPo battery to power the TeleMega.

The TeleDongle does not come with an antenna. This probably seems odd at first, but there are a lot of antennas available, or you can build one yourself. In general, you want a Yagi antenna. The Yagi antenna is a directional antenna, which means you need to keep it pointed in the general direction of the rocket to get a strong signal. Yagi antennas can also pick up a much weaker signal than a simple dipole antenna, though, so they can track a rocket to extreme heights.

All antennas are built to pick up a specific frequency, but they work well across a narrow range of frequencies. The TeleMega operates in the 70 cm amateur radio band, which corresponds to a wavelength of 428 MHz. When specifying the frequency, though, this is usually rounded a bit to 440 MHz. That explains the catalog numbers for the recommended antennas from Arrow Antenna, the 440-3 or 440-5. The last digit is the number of elements in the antenna. Figure 10-8 shows the Arrow 440-3, with three elements. In general, as the number of elements goes up, the antenna is more directional and will pick up a weaker signal. For most flights, the 440-3 is a great choice. It won't pick up a signal quite as well as the 440-5, but it doesn't have to be pointed as accurately, either. You can also build your own antenna following directions from various online sources. I built the eight-element Yagi antenna shown for just a few dollars, and it works quite well.

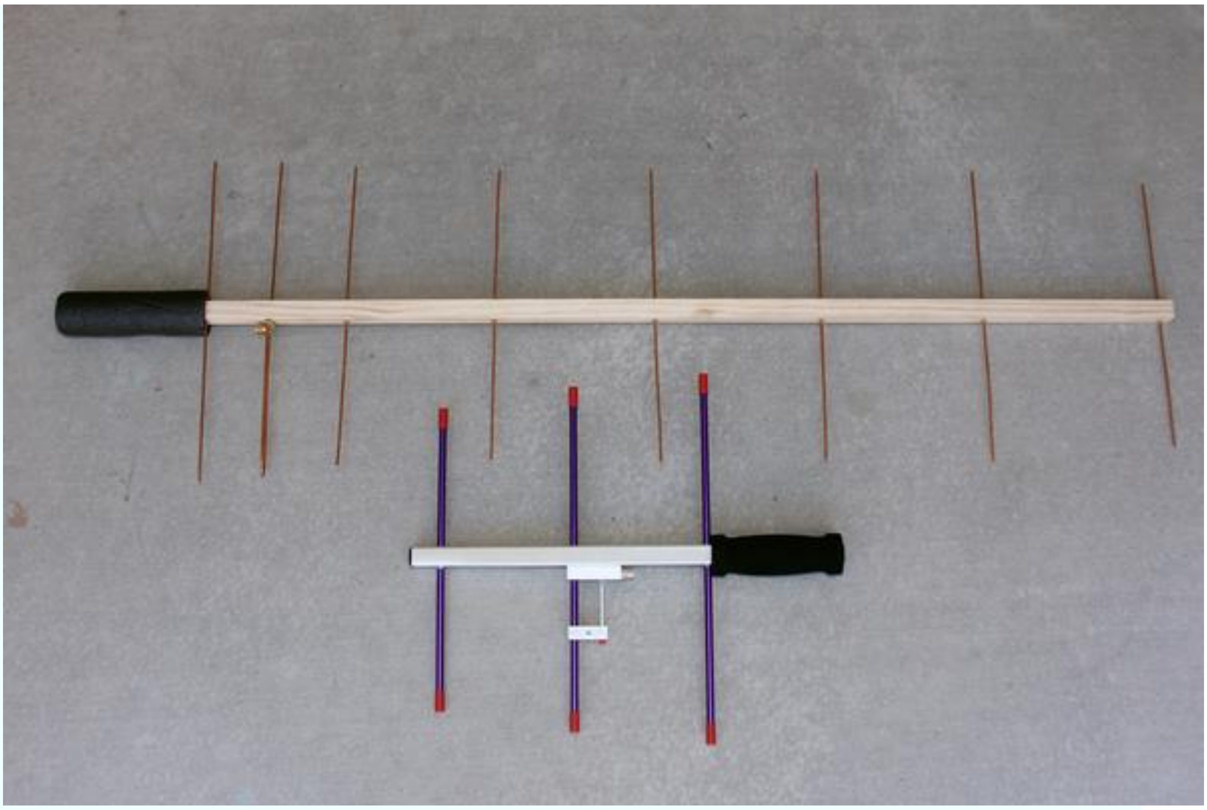


Figure 10-8. The Arrow 440-3 Yagi antenna (bottom) works well with the TeleDongle, although you can also build your own for a few dollars.

If you would like to build your own antenna, you will need to learn a bit about antenna theory to get the dimensions right, but a Yagi antenna is essentially a series of conducting rods, easily made from copper or aluminum tubes or rods, or from thick wire like the one seen here. Search the web if you are interested. There are a number of sites for people with different backgrounds in mathematics, physics, and electrical engineering, from simple how-to guides to sites that delve into the fascinating field of antenna theory.

Many antennas, including the Arrow 440-3 and Arrow 440-5, use a connector called a BNC connector. Like the SMA connector on the TeleDongle, BNC connectors have a male and a female plug. The plug on the Arrow antennas is a female plug, so you will also need an SMA-BNC adapter with male plugs on both sides (see Figure 10-10). The antennas and adapters are available from many online retailers, including Amazon.

The Technician Class Radio License

Operating radio transmitters in most frequency ranges requires an FCC radio license. There are a few exceptions, like low-power transmissions using some walkie-talkies, cell phones, and WiFi communications. The TeleMega and most directional radio trackers use frequencies that require a license.

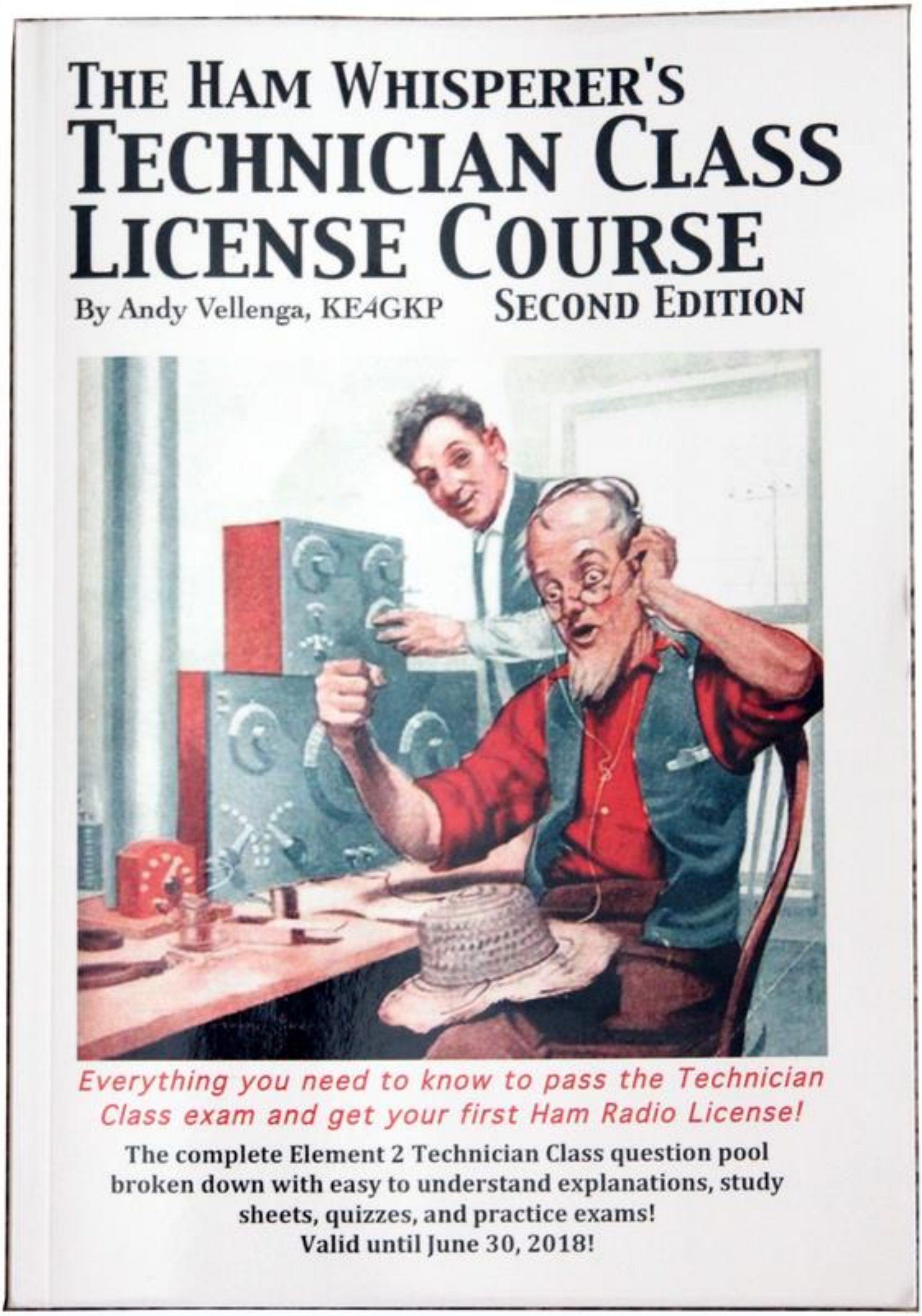
There are currently three levels of licenses for amateur radio operators. The one needed to operate the TeleMega is called the Technician Class. To get it, you need to take a 35-question multiple-choice test. Like the Level 2 rocketry test (covered in the next chapter), this test is taken from a question pool. The current test pool has 396 questions from which the 35 question tess are drawn.

There are several approaches to this test. The first, and best, is to study radios and electronics so you understand what amateur radio is all about, and then get involved with the amateur radio community. If you want to take that approach, start with the American Radio Relay League (ARRL) website. The ARRL also puts out a wide variety of great books on amateur radio. A good one to start with is the *ARRL Operating Manual*, available from the ARRL website or Amazon.

You can also find online courses and classes. The ARRL website is one place to look for them, but check with your local radio clubs and community colleges, too.

At the risk of upsetting some of my amateur radio friends, though, there is another approach. If your only reason for getting the license is to operate a TeleMega or similar device, pick up one of the many study guides, like the one seen in Figure 10-9. These lead you through the question pool, giving you the correct answers and just enough background to understand the answers. They are far from a complete course in amateur radio, but they will quickly and efficiently get you the Technician Class license you need to find your rockets.

However you choose to study, once you’re ready for the test, head back to the ARRL website and follow the links for licensing and the exams. Enter your zip code and the site will list exams near you in the next few months.



THE HAM WHISPERER'S TECHNICIAN CLASS LICENSE COURSE

By Andy Vellenga, KE4GKP

SECOND EDITION

Everything you need to know to pass the Technician Class exam and get your first Ham Radio License!

The complete Element 2 Technician Class question pool broken down with easy to understand explanations, study sheets, quizzes, and practice exams!

Valid until June 30, 2018!

Figure 10-9. One of the many books that can help you study for the Technician Class license is The Ham Whisperer's Technician Class License Course.

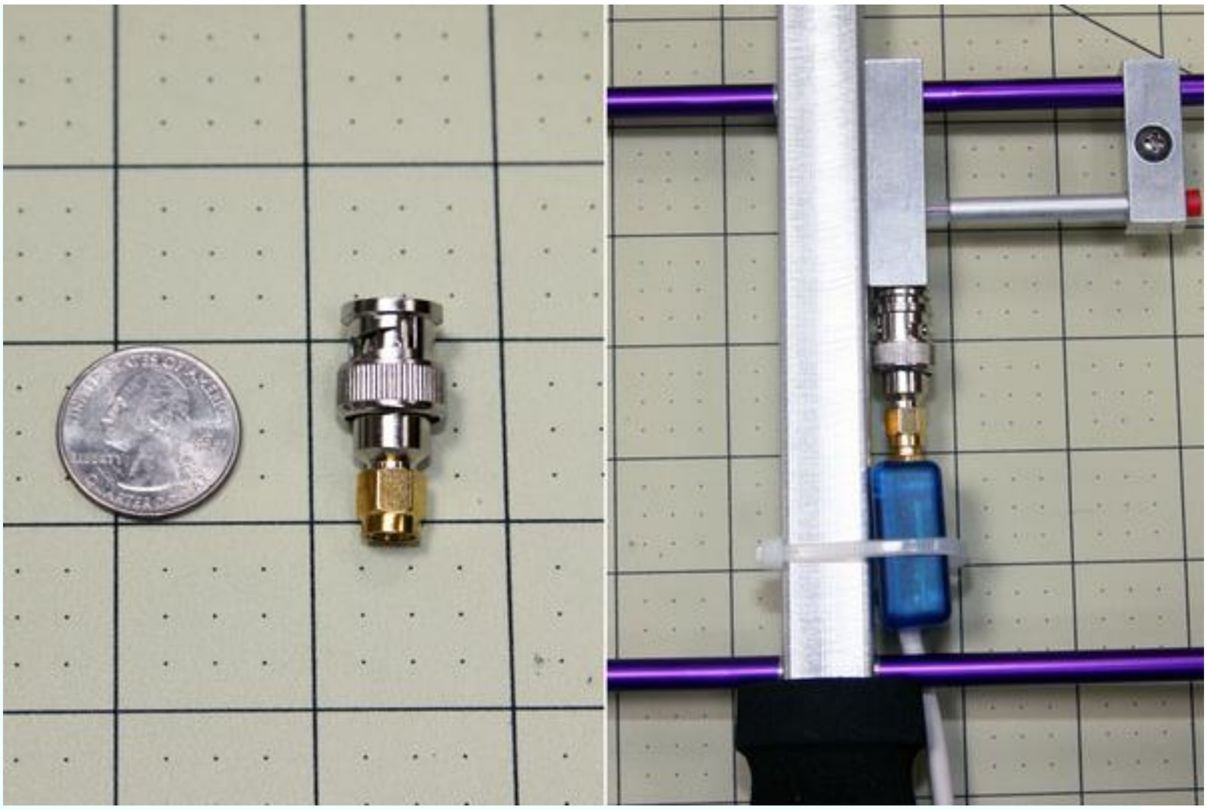


Figure 10-10. The TeleDongle connects to the Arrow 440 antennas using a male-to-male SMA-BNC adapter. Here you see the adapter, as well as the TeleDongle attached to the antenna with the adapter.

That's all you need to get started with the TeleMega, but there are a few other items to consider. The quarter wave dipole antenna, which is the cool name for the wire hanging off of the TeleMega, is a fine antenna for most purposes. It will work well with all of the rockets in this book. If you start flying to 20,000 feet or more, though, you might want to replace the antenna with a slightly better one. The TeleMega is designed to make this fairly easy, but you do need to feel comfortable enough with a soldering iron to desolder and solder components directly to the TeleMega. Take a look at Figure 10-11. You will need to desolder the antenna that is currently on the board. The PCB Mount SMA Straight Jack Receptacle, RadioShack part 278-0019, slides into place with the center pin connecting where the antenna used to connect and two of the legs attaching to solder pads on the opposite side of the board.

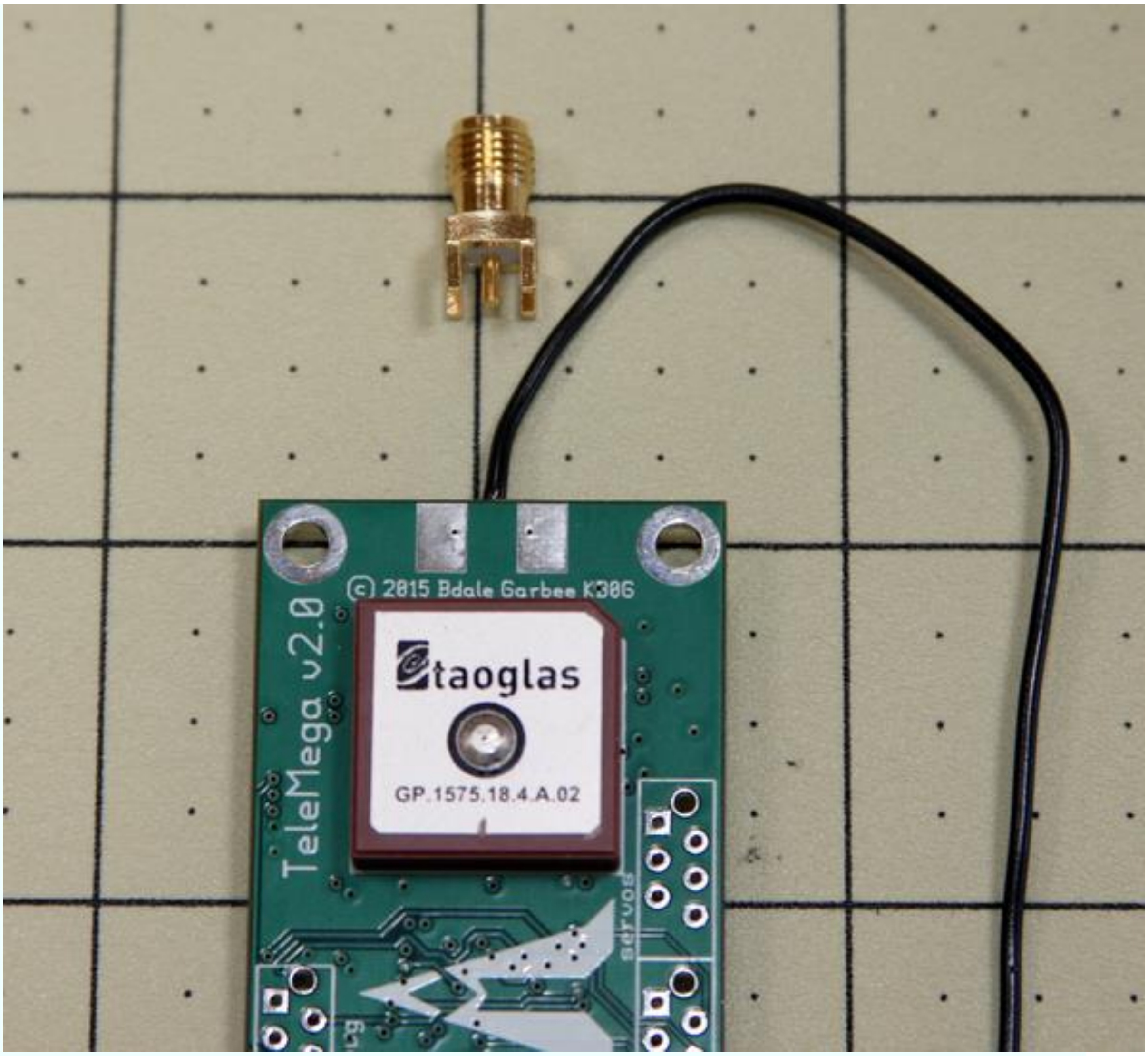


Figure 10-11. The TeleMega antenna can be replaced with an SMA connection. This can be used to connect the TeleMega to other antennas.

One good choice for a better antenna is the Link Technologies ANT-433-CW-RH-SMA-ND, available from DigiKey and other online electronics suppliers. I don’t recommend attaching the antenna directly to the SMA connector soldered on the TeleMega, though. A rocket undergoes a lot of vibration during flight. It would be a shame to lose the signal, and possibly the rocket, because the antenna vibrated the connection loose. Attach a cable between the SMA connector and the antenna, instead, as you see in Figure 10-12. There are a variety of connectors and cables you can use, depending on exactly how your electronics bay is designed. Figure 10-12 also shows the antenna mounted on a metal bulk plate that acts as a ground plane, directing the signal a bit away from the ground plane. It’s a great setup for a bulk plate that faces the ground while the rocket is in flight.

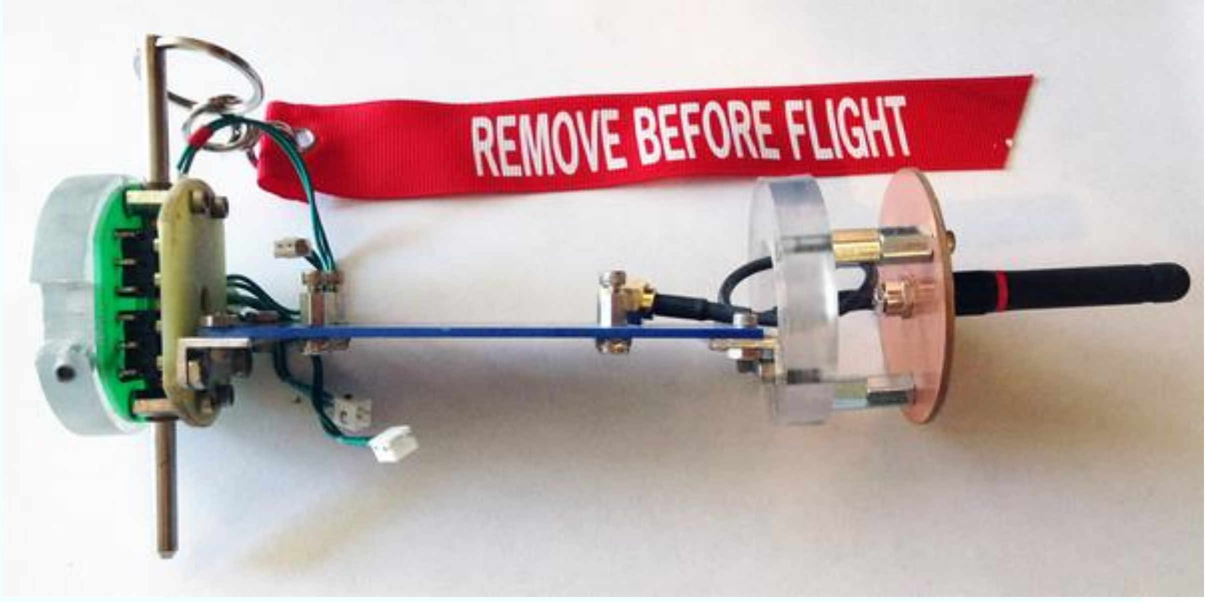


Figure 10-12. Stephen Forbes uses a conducting ground plane and a cable to reduce strain on the joint on the TeleMega. Photo courtesy of Stephen Forbes.

Software

Once you collect all of the hardware for the TeleMega, download and install the software from the Altus Metrum website. Altus Metrum makes the software for the ground station available for Windows, macOS, and Linux, so pretty much any computer will work.

Connect the TeleDongle to your computer using a free USB port. Connect the TeleMega to another USB port using the USB to micro-USB cable, and connect the battery to the TeleMega. Finally, turn it on! There are two terminals on the terminal block labeled “switch.” You can either install an actual switch or just wire these contacts together with a bit of wire, as seen in Figure 10-13.

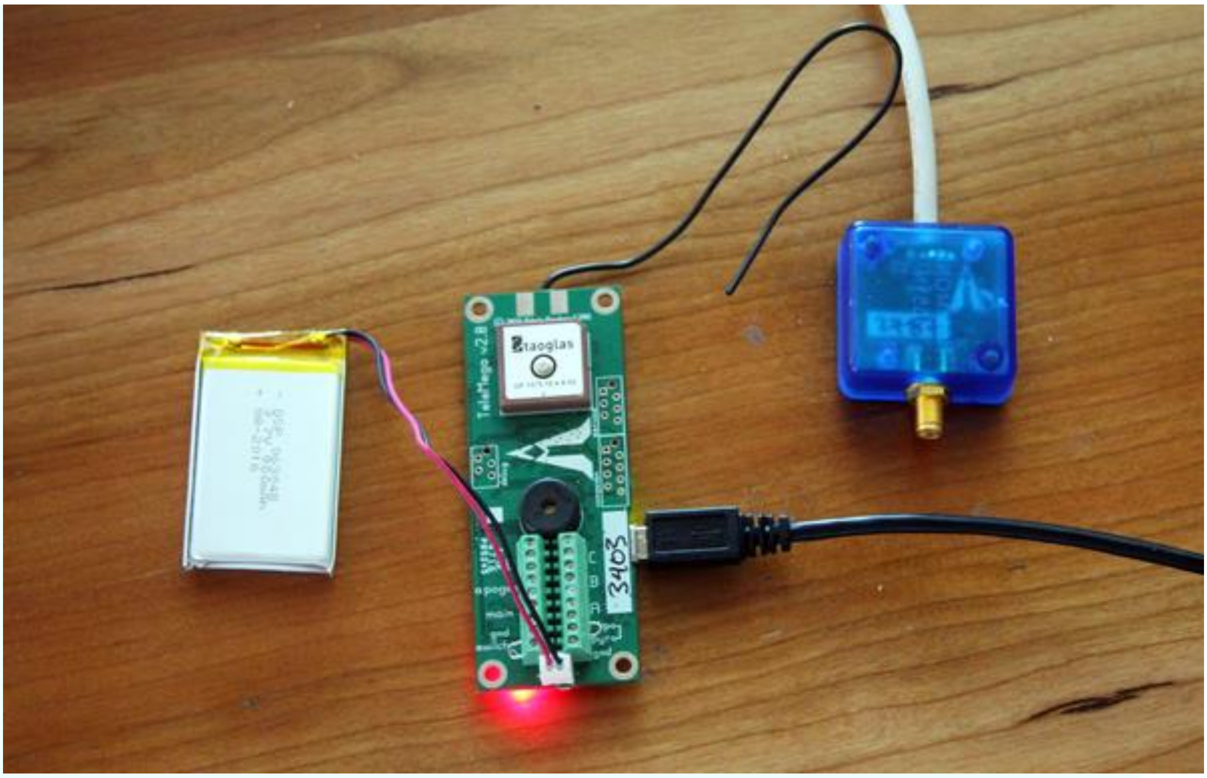


Figure 10-13. Connect your TeleDongle and TeleMega to USB ports on your computer, connect a battery to the TeleMega, and wire the switch contacts together to turn the device on.

Start the AltosUI application. You will see two windows, one with a number of buttons to select other functions, and one used during flight. For now, close the one used during flight, leaving the window shown in Figure 10-14.

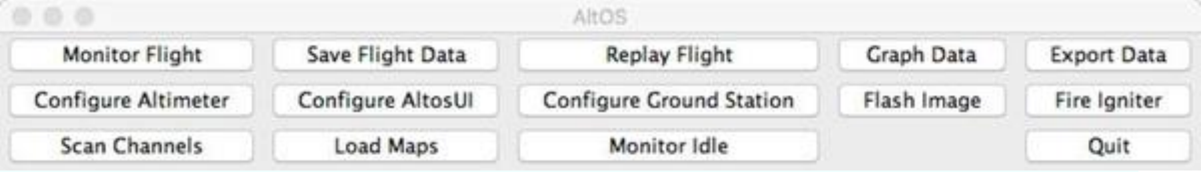
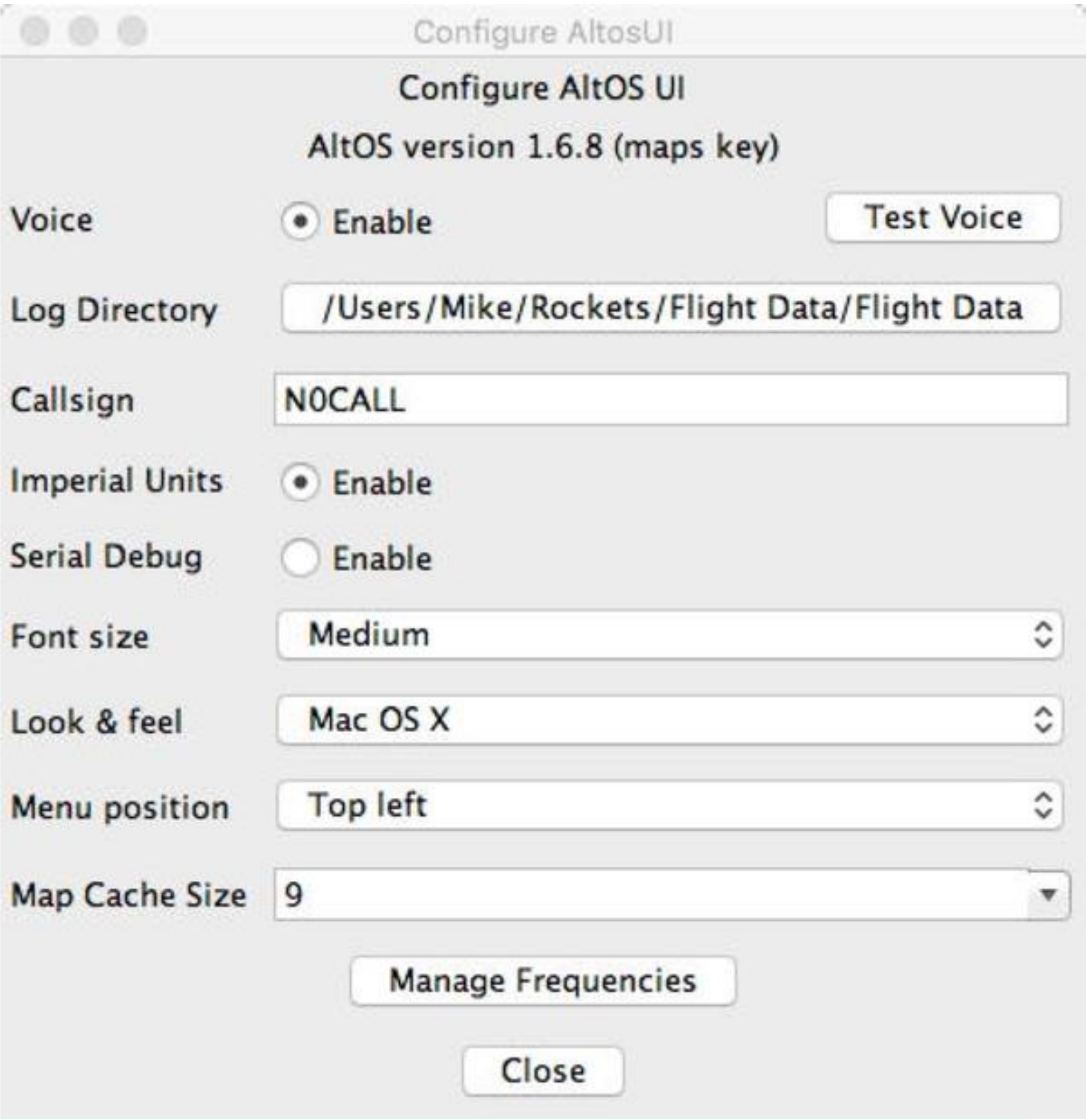


Figure 10-14. The startup window for AltosUI.

Click the Configure AltosUI button. This brings up the dialog in Figure 10-15.



Configure AltOS UI

AltOS version 1.6.8 (maps key)

Voice ● Enable

Log Directory /Users/Mike/Rockets/Flight Data/Flight Data

Callsign N0CALL

Imperial Units ● Enable

Serial Debug ○ Enable

Font size Medium

Look & feel Mac OS X

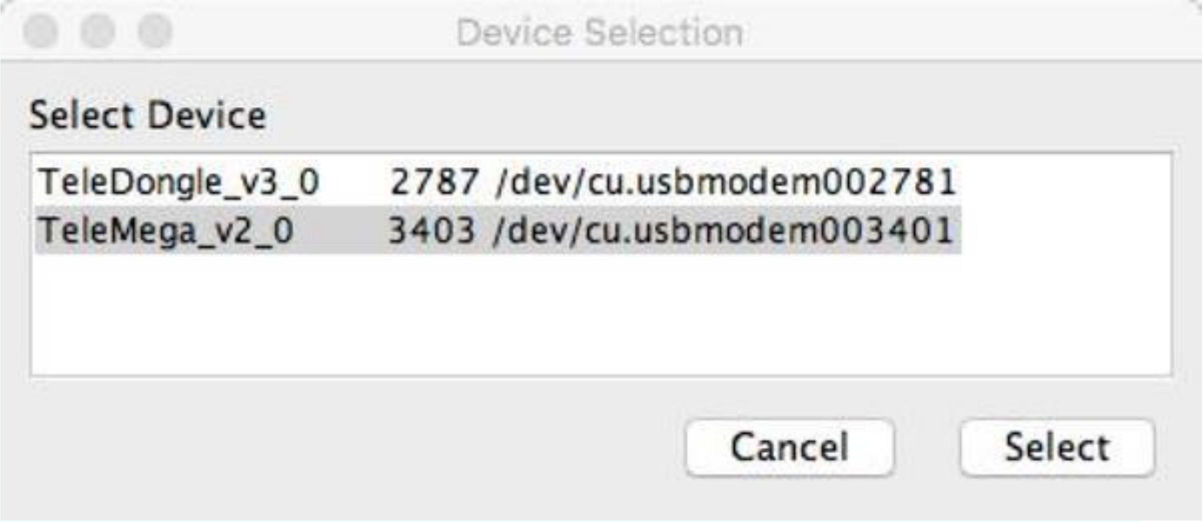
Menu position Top left

Map Cache Size 9

Figure 10-15. This dialog is used to set your callsign.

There are a number of options in this dialog, but the important one for our current purpose is the callsign. Enter your FCC callsign here and click the Close button.

Back in the startup window, click the Configure Altimeter button. This brings up a dialog used to select a device (Figure 10-16). The altimeter is the TeleMega, so choose that device and click Select.



TeleDongle_v3_0 2787 /dev/cu.usbmodem002781
TeleMega_v2_0 3403 /dev/cu.usbmodem003401

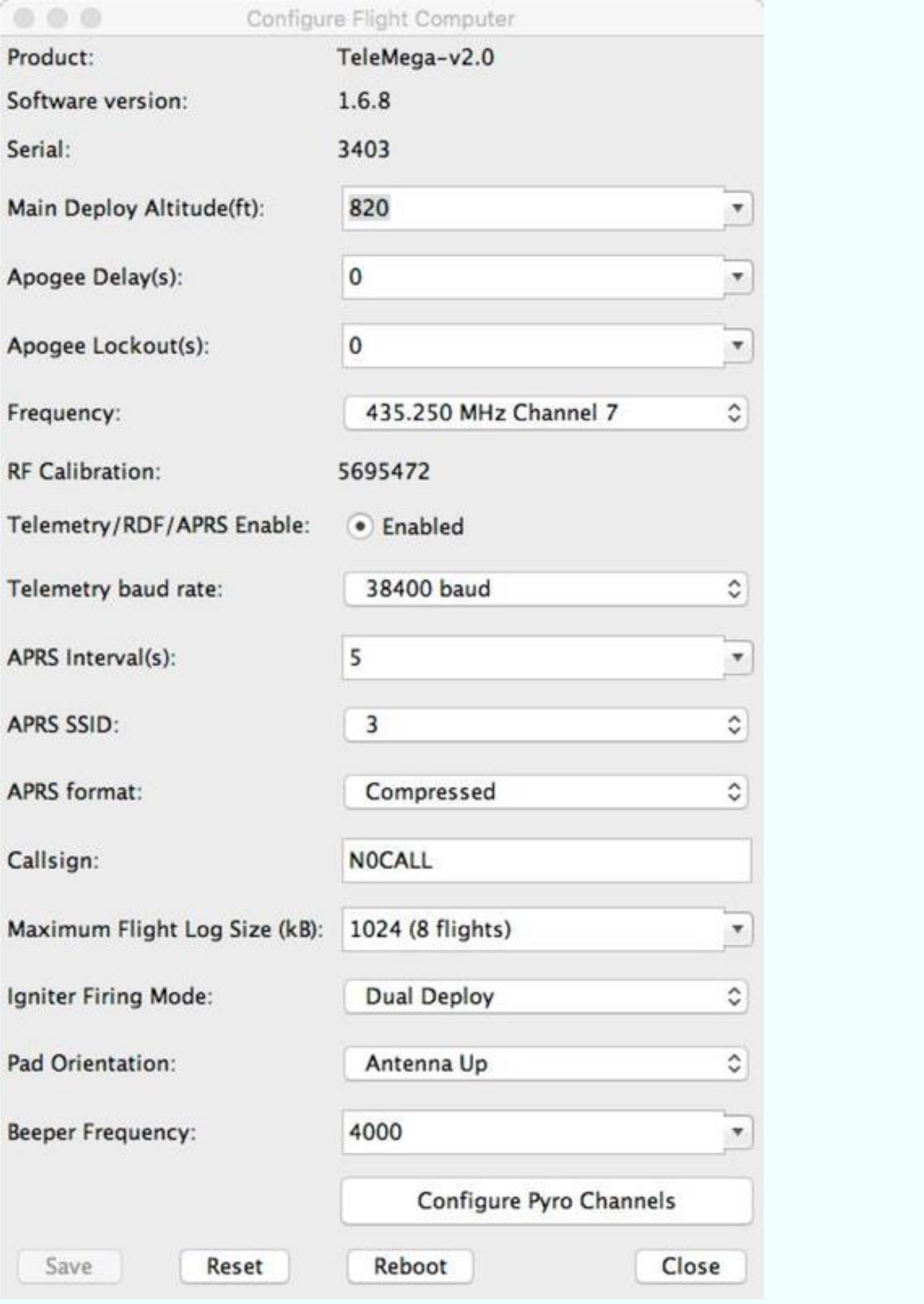
Figure 10-16. This dialog appears to select an altimeter or ground station.

Selecting the altimeter brings up the dialog in Figure 10-17. There are several options which are probably familiar from the discussion of altimeters in Chapter 7. We'll gloss over those for now, but if they are not obvious, you can find details in the documentation that downloads with the AltosUI software.

The Frequency setting chooses one of 10 channels, each with a specific frequency, that the ground station and altimeter will use for communication. This may need to be reset at the launch site to keep from interfering with other fliers who are also using the TeleMega or another radio that operates in the 70 cm band. Select one of the 10 channels.

The TeleMega determines its startup mode and detects launch depending on the orientation of the accelerometer. You can change this using the Pad Orientation setting. Select Antenna Up or Antenna Down based on how the radio will be mounted in the rocket.

Enter your callsign again. Check the various other settings to make sure the obvious ones make sense. Unless you spend some time with the manual to learn what the settings are for, leave all other settings, like the Telemetry baud rate, with their default settings. Once you've entered the settings shown in Figure 10-17, click Save and then Close to exit out of the dialog.



Product: TeleMega-v2.0

Software version: 1.6.8

Serial: 3403

Main Deploy Altitude(ft): 820

Apogee Delay(s): 0

Apogee Lockout(s): 0

Frequency: 435.250 MHz Channel 7

RF Calibration: 5695472

Telemetry/RDF/APRS Enable: ● Enabled

Telemetry baud rate: 38400 baud

APRS Interval(s): 5

APRS SSID: 3

APRS format: Compressed

Callsign: N0CALL

Maximum Flight Log Size (kB): 1024 (8 flights)

Igniter Firing Mode: Dual Deploy

Pad Orientation: Antenna Up

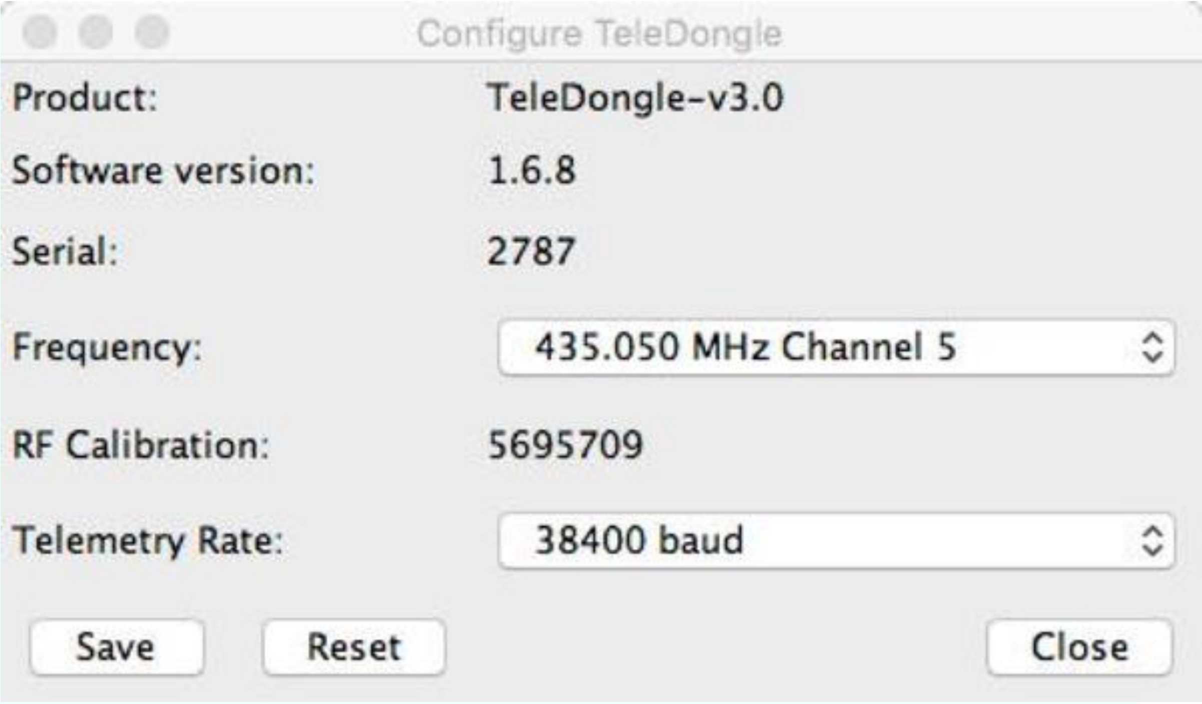
Beeper Frequency: 4000

Figure 10-17. Use this dialog to configure the TeleMega.

TIP

If a dialog pops up saying the TeleDongle is already in use, unplug it from the USB port, wait a minute or so, and plug it back in.

Click the Configure Ground Station button to set up the ground station using the dialog shown in Figure 10-18. The important setting is the Frequency, which must match the frequency selected for the TeleMega. Once you've entered the settings shown here, click Save and then Close to exit out of the dialog.



Configure TeleDongle

Product: TeleDongle-v3.0

Software version: 1.6.8

Serial: 2787

Frequency: 435.050 MHz Channel 5

RF Calibration: 5695709

Telemetry Rate: 38400 baud

Figure 10-18. Configure the ground station by selecting the frequency for the TeleMega.

TIP

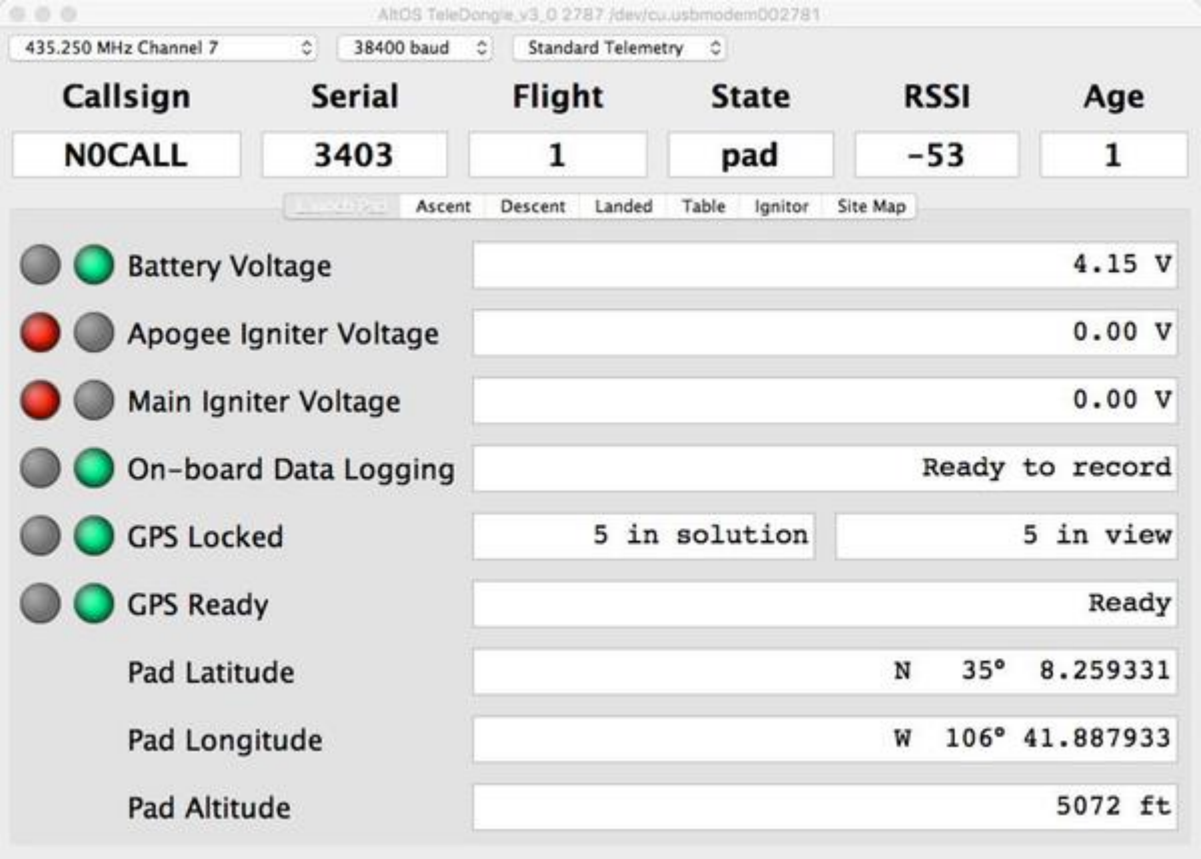
You can use your ground station to listen to other TeleMega devices besides your own. At our own launches, when someone flies with a TeleMega, several people will track the rocket with their ground stations. That helps if one of the people loses the signal due to pointing the antenna in the wrong direction, pulling a cable loose, or some other misfortune.

Flying with the TeleMega

The process of setting up charges, making connections, and preparing the rocket for flight using the TeleMega is the same as with other altimeters covered in “Choosing an Altimeter”. The only difference lies entirely in the additional steps needed to work with the GPS and radio transmitter. You can simulate that for the first time right at your desk.

With the TeleDongle ground station and the TeleMega flight computer connected to your computer through a USB port, the battery connected to the TeleMega, and the TeleMega switched off, start the AltosUI software. It doesn’t hurt to connect an antenna to the TeleDongle, but at a range of a few inches, it isn’t really necessary, either.

The dialog shown in Figure 10-19 should appear. If not, click the Monitor Flight button in the startup window and select your TeleDongle from the device selection dialog. Check the connections if it does not appear.



435.250 MHz Channel 7 | 38400 baud | Standard Telemetry

Callsign	Serial	Flight	State	RSSI	Age
N0CALL	3403	1	pad	-53	1

Battery Voltage	4.15 V	
Apogee Igniter Voltage	0.00 V	
Main Igniter Voltage	0.00 V	
On-board Data Logging	Ready to record	
GPS Locked	5 in solution	5 in view
GPS Ready	Ready	
Pad Latitude	N 35° 8.259331	
Pad Longitude	W 106° 41.887933	
Pad Altitude	5072 ft	

Figure 10-19. The initial flight dialog.

The start process takes a couple of minutes. Assuming your computer speaker is on, you will hear the ground station say “Startup,” followed quickly by “Pad,” indicating the TeleMega has been found and is oriented for launch.

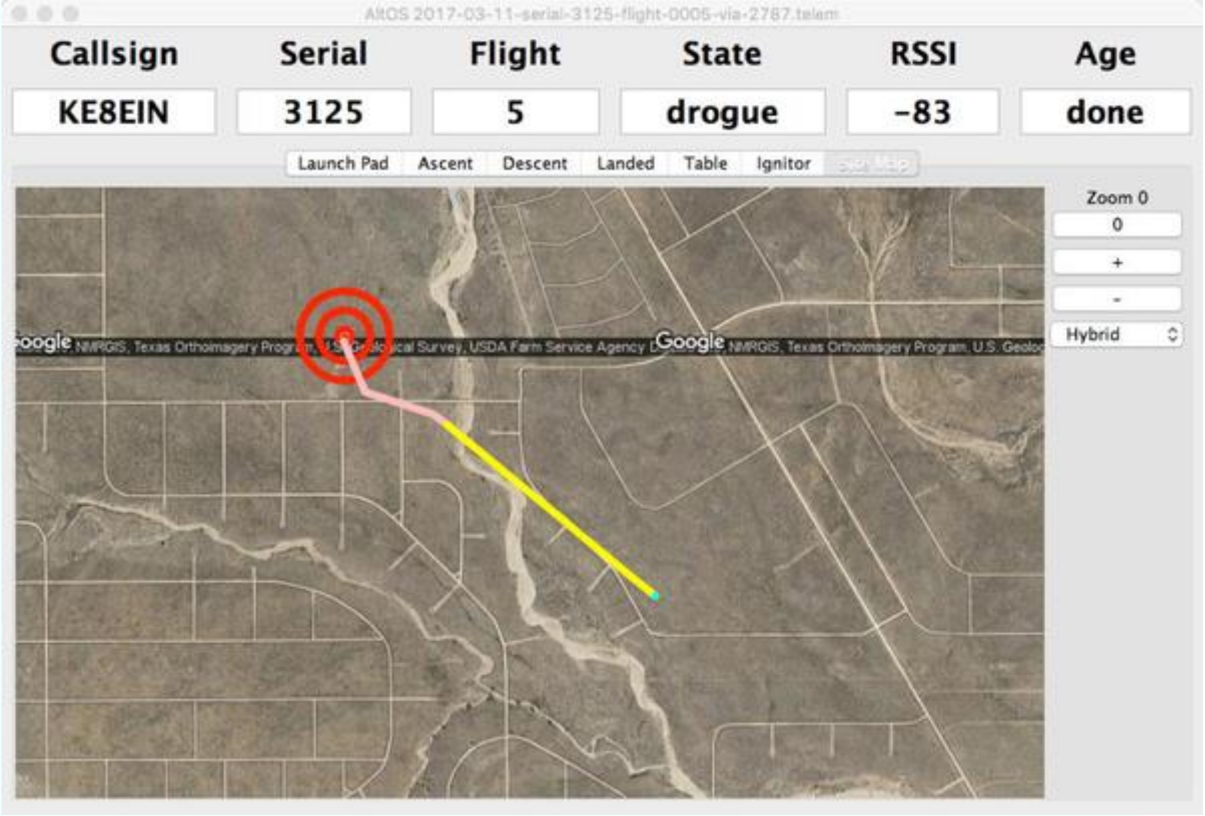
Gradually, the number of GPS satellites in view will increase. Once enough satellites are in view and locked, the ground station announces “GPS ready,” and the dialog is filled in more or less like what you see in Figure 10-19. You can see that no charges are connected to the computer. In an actual launch, the apogee and main igniter indicators should be green, which tells you the charges have continuity.

On the flight range for your first flight, the ground station will continue to announce information as the flight takes place. You will hear announcements for the start of boost, maximum speed, and when the coast phase starts. For a long flight, the altitude will be announced several times, followed by the maximum altitude.

The voice output gets really useful as the rocket descends. It is pretty easy to keep the ground station antenna pointed in the right direction during boost. The rocket goes up, and to a very close approximation, your antenna also just needs to be pointed up. Once the drogue parachute deploys, though, there may be significant drift. The ground station will announce the direction as a compass heading, such as south-south-west, and the elevation above the horizon in degrees. This helps you point the antenna even when you can’t see the rocket.

Finally, the flight station gives the location where the rocket landed.

There is a wealth of information you can glean from the AltosUI software. The GPS coordinates for landing are the most useful. Another feature that can be a big help is the site map, which shows the flight path and landing spot on Google Maps (see Figure 10-20).


AltOS 2017-03-11-serial-3125-flight-0005-via-2787.telem

Callsign	Serial	Flight	State	RSSI	Age
KE8EIN	3125	5	drogue	-83	done

Launch Pad
Ascent
Descent
Landed
Table
Ignitor
Site Map
Zoom 0
0
+
-
Hybrid
Google
NMRGIS, Texas Orthoimagery Program, U.S. Geological Survey, USDA Farm Service Agency

Figure 10-20. The map view shows the landing location on Google Maps.

The Altus Metrum system is not the only GPS solution available, but it is a very good one. There is one other feature of the system that makes it particularly attractive for people who like to tinker: both the hardware and software are available under open licenses. Source code, schematics, and PCB artwork are all available for download from the Altus Metrum website.

Other GPS Solutions

Before leaving the subject of GPS, let’s get a bit creative. While an integrated altimeter and GPS system with fancy flight software is a very attractive option, there are others. An inexpensive flight computer handles dual deployment nicely for well under $100. With some creative repurposing, you can add GPS inexpensively, too.

Figure 10-21 shows one example. This is a GSM/GPS tracker that uses a combination of cell phone and GPS technology. There are some disadvantages, specifically that you need an extra SIM card for the device itself, and both your cell phone and the device have to be in range of a cell tower. Still, you can pick up devices like this one for just a few dollars and repurpose the SIM card from an old cell phone for a flight. After the flight, you call the GPS device from a cell phone and get back a text message with the GPS coordinates of the landing site.

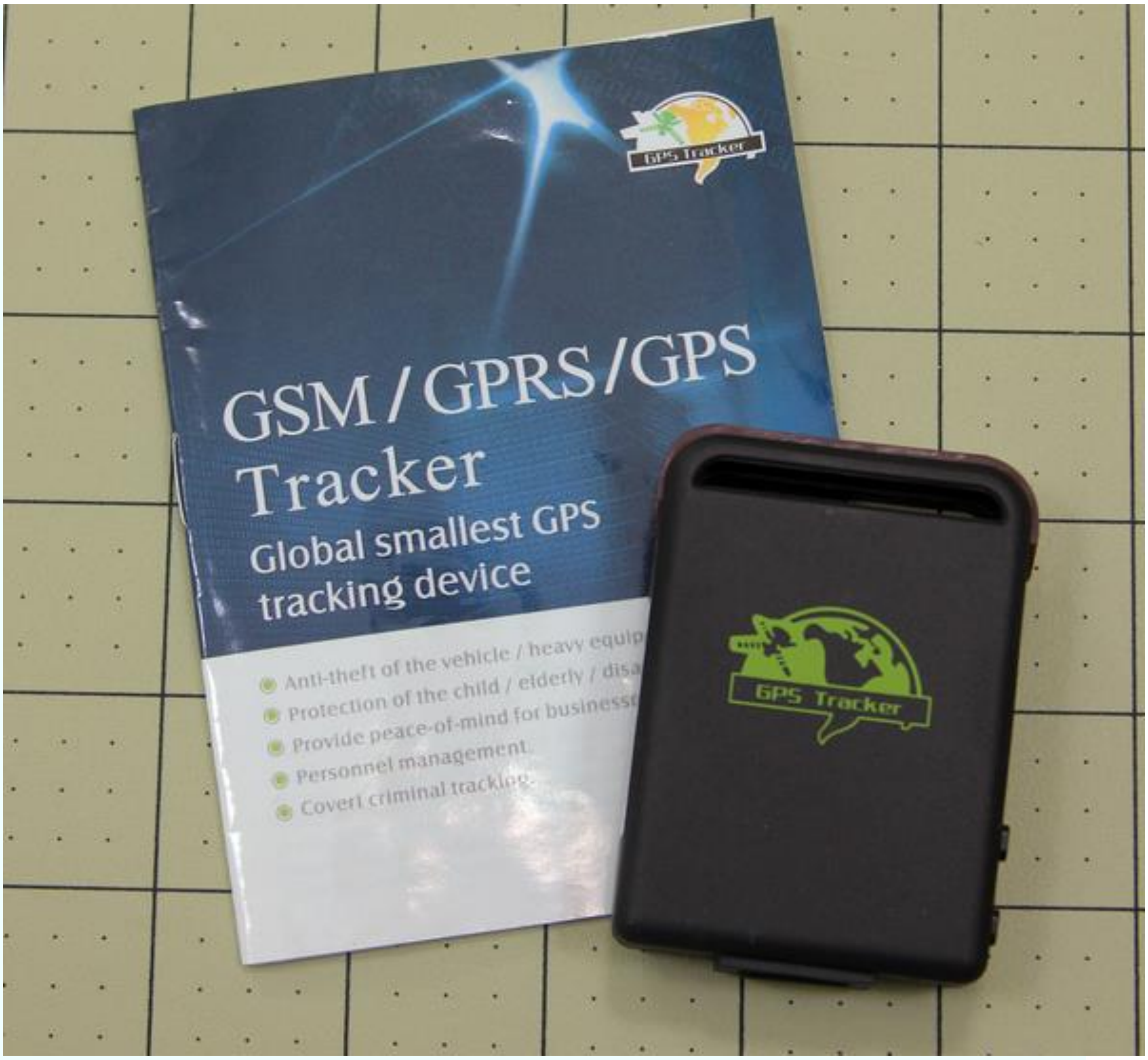


Figure 10-21. Many GPS devices can be repurposed for use in rocketry.

There are lots of other alternatives, with the list growing constantly. Another example is a dog tracker. So, if you aren’t quite ready for a TeleMega but want to give GPS a try, crank up your search engine and look around on the web for an alternative that will work in your area.

hapter 11. The Level 2 Exam

You had to build and successfully fly a rocket that used an H or I motor for your Level 1 certification. There are two parts to the Level 2 certification: the first is a lot like the Level 1 certification, but with a bigger motor (one in the J, K, or L class), and the second part of the certification is to pass a written exam. This chapter gets you ready for that exam.

There are two great ways to study for the Level 2 exam. The first, and I think the most fun, is to learn a lot about high-power rocketry. If you read this book from the beginning through this chapter and reviewAppendix B, you will be more than ready for the Level 2 exam. In fact, you can still skip all of the math except the way total impulse relates to letter designations (see Chapter 1) and still be overprepared.

The second way is to download the test and take a look. Both NAR and TRA publish their tests online. The NAR test consists of 37 questions taken from a pool of 97 questions. That pool of questions is the online test. You must get 32 of the 37 correct to pass. The TRA test is similar; it consists of 50 questions from a pool of 100, and you must get 45 or more correct. We’ll cover where to find the tests later.

Everyone is different, and I suspect by now that you know best how to prepare for tests. My recommendation is to read the book through this chapter, study Appendix B, and then download the online test for the agency you’ve picked and take that full test. Grade yourself, and be sure to review any questions you missed. After that, the actual test should be pretty easy.

Test day can take a lot of different forms. You are already familiar with your local rocket club and the people in the club who help certify rocketeers from when you got your Level 1 certification. Get in touch with them and find out how they generally handle the test. Some give the test before club meetings, which is how I took mine. Some will arrange a quiet place to meet where you can take the test without anyone else around. Some will give you the test on launch day. It’s really up to you and the examiner. Talk to them sooner rather than later, so you know what to expect.

Rocketry and the Law

One of the attractions of rocketry is that it spans such a broad area of technologies. The downside is that this also means rocketry is governed in different ways by a variety of organizations. This section takes a look at the big three: the Federal Aviation Administration (FAA); the Bureau of Alcohol, Tobacco, Firearms, and Explosives (BATFE, often shortened to ATF); and the National Fire Protection Association (NFPA). The NFPA doesn’t actually implement or enforce laws, but its recommendations are often adopted into law, usually unchanged, by many states. We also end up dealing with Department of Transportation (DOT) rules for shipping motors. We’ll cover that briefly, too.

CAUTION

Before going any further, it’s worth pointing out that the laws are rather fluid. You might read online articles and books that give you different information than what you see here. They were probably correct when they were written, just as this book is, but things change. Your local rocketry club and the NAR and TRA websites are a good source of information for keeping up to date.

The Federal Aviation Administration (FAA)

The FAA is responsible for keeping the airways safe in the United States. Similar organizations exist in most other countries, often with regulations that are pretty close to the ones covered here. If you are outside the United States, check with your local rocket club or online to find current information.

The FAA is concerned with how heavy our rockets are and how high they go. It cares about the fuel weight, too, since that’s the highly combustible material in the rocket. As such, the FAA divides hobby rocketry into three classes, outlined in a document called 14 CFR 101. If you are curious about other forms of model aviation, the same regulation also covers kites and unmanned balloons, although we won’t go into those here.

Class 1 rockets are the small rockets typically flown by schools, scouts, and hobbyists in parks and small fields across the country. The FAA defines a Class 1 rocket as any rocket that:

1. Uses no more than 125 grams (4.4 ounces) of propellant;
2. Uses a slow-burning propellant;
3. Is made of paper, wood, or breakable plastic;
4. Contains no substantial metal parts; and
5. Weighs no more than 1,500 grams (53 ounces), including the propellant.

The FAA doesn't generally care about Class 1 rockets, as long as they are not flown near airports or other restricted airspace.

A Class 2 rocket is any rocket that isn't a Class 1 rocket and that has one or more motors with a combined total impulse of 40,960 N-s or less. For a single motor, that's an O motor or smaller. All of the rockets in this book are either Class 1 or Class 2 rockets, depending on the motor you use.

A Class 3 rocket is any amateur rocket that doesn't fit into one of these categories.

Notice that there is no mention of total impulse when distinguishing between a Class 1 and a Class 2 rocket. The only distinctions are the mass of the rocket, the materials it is built with, and the propellant type and mass. Many H motors, including the ones described in detail for Callisto's Level 1 flight, use less than 125 grams of propellant. As far as the FAA is concerned, those are Class 1 rockets, and fly under the same rules as a small hobby store rocket.

There are some technical requirements listed in the regulation, but in practice, the rules for Class 1 rockets are pretty simple. As long as you are following the NAR or TRA safety code, the FAA does not place any restrictions on Class 1 rockets. There may be other restrictions, but the FAA is not the agency imposing them.

While there are a few corner cases, like small H motors, the FAA classification of the Class 2 rocket is essentially the same as what we think of as high-power rocketry. It generally includes the rockets in this book, and covers the range of the Level 1, 2, and 3 certifications.

There are some important restrictions on Class 2 rockets. Your club has undoubtedly been following them as you got started, with the RSO and FSO making sure the rules are followed. Some of the rules are also encoded in the TRA or NAR safety codes. Let’s take a look at them. 14 CFR 101.25 states that you are not allowed to fly a Class 2 or Class 3 rocket:

1. At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;
2. At any altitude where the horizontal visibility is less than five miles;
3. Into any cloud;
4. Between sunset and sunrise without prior authorization from the FAA;
5. Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;
6. In controlled airspace without prior authorization from the FAA;
7. Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:
    1. Not less than one-quarter the maximum expected altitude;
    2. 457 meters (1,500 ft.);
8. Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and
9. Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

You are allowed to break three of those rules if you have prior authorization from the FAA. That authorization usually takes the form of the Class 2 waiver you have no doubt heard people in your local club talking about. While you don’t need a waiver at all to fly a Class 2 rocket if you follow all of these rules, from a practical standpoint, the rule about flying into controlled airspace means you need a waiver for any high-power rocket that is not a Class 1 rocket. Controlled airspace is low enough over most of the United States that you usually hit controlled airspace when you fly a high-power rocket. If you want to split hairs, you're welcome to learn about the FAA regulations governing controlled airspace, but the boundaries of controlled airspace can change very quickly, so I can't give a useful definition here.

The process for filing a waiver changes from time to time. What follows are the current procedures, which will give you a good idea of what is involved, but it's wise to check the NAR or TRA website for updated information before filing for a waiver. Both NAR and TRA stay in touch with the FAA, and the FAA in turn lets them know when procedures change.

The waiver itself is filed with one of the FAA's regional offices. You can find a list of the offices and contacts on the TRA web site or the NAR website. There are three regional offices, each of which oversees a block of states. The waiver application itself is filed using FAA Form 7711-2, which you can find on the FAA website.

The waiver asks for several pieces of information, including:

1. Estimated number of rockets.
2. Type of propulsion (liquid or solid), fuel(s), and oxidizer(s).
3. Description of the launcher(s) planned to be used, including any airborne platform(s).
4. Description of the recovery system.
5. Highest altitude, above ground level, expected to be reached.
6. Launch site latitude, longitude, and elevation.
7. Any additional safety procedures that will be followed.

You must file the form, in triplicate, at least 45 days before the launch, but allowing more time is always a good idea. You must also attach a map that shows the launch site layout, including fire extinguisher locations. The waiver can ask for an extended period of time, too. The rocketry clubs in New Mexico routinely ask for a waiver for a one-year period.

It takes a fair amount of time to do the research needed to fill out the FAA Form 7711-2, but once it has been completed for a particular launch site, refiling it from year to year is pretty routine. That's one of the great things about a rocket club: all of this work is done for you. If you happen to be the one filing the form, it's probably been done before for a particular launch site, so you just have to update the filing from the previous year. If you do have to file a waiver, be sure to stop by the NAR website. The documentation there provides an excellent description of all of the steps, along with helpful hints about where to get the additional information you need and how to fill out the form for a successful approval.

Once the waiver is approved, you still need to make a call to the local FAA office before each launch. I mentioned that there are a few technical, but impractical, loopholes that might allow flying a Class 2 rocket without a waiver. You still need to notify the FAA of any Class 2 launch, though, whether a waiver is required or not. You do that with a call to the local Air Traffic Control (ATC) facility. Here is the information, straight from 14 CFR 101.27, that you need to provide:

No person may operate an unmanned rocket other than a Class 1—Model Rocket unless that person gives the following information to the FAA ATC facility nearest to the place of intended operation no less than 24 hours before and no more than three days before beginning the operation: (a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event; (b) Date and time the activity will begin; (c) Radius of the affected area on the ground in nautical miles; (d) Location of the center of the affected area in latitude and longitude coordinates; (e) Highest affected altitude; (f) Duration of the activity; (g) Any other pertinent information requested by the ATC facility.

You can find listings for ATC facilities by doing a web search for "FAA ATC facilities." One such website is *http://www.air-traffic-control.com/faa-atc-facilities/*.

The person you talk to may not be familiar with the regulations—they are normally concerned with airplanes, not rockets, after all. Mention the waiver you filed and with whom, and tell them you are providing the information as outlined in 14 CFR 101.27. That should put them at ease.

Be prepared for other questions or requests. As an example, our ATC asks us to call in just before we start launch activities, and again right after we finish.

The FAA will create a Notice to Airmen, or NOTAM, to tell pilots to stay out of the airspace you have reserved. You can check these online at *https://pilotweb.nas.faa.gov/PilotWeb/*.

Class 3 rockets are handled on a case-by-case basis. The FAA asks for a Class 3 waiver for any flight that is not a Class 1 or Class 2 flight, and currently also asks for a Class 3 waiver for any flight over 50,000 feet. TRA has an annual research launch at Black Rock, Nevada, called BALLS (Bad Ass Load Lifting Suckers), where Class 3 flights and experimental flights are common. The last year I attended, the FAA was granting altitude waivers up to 495,000 feet, and an FAA representative was on hand at the launch. TRA has a well-oiled system for getting Class 3 waivers. Be sure to check with this organization if you are planning a Class 3 flight, whether it is at BALLS or not.

You might ask why the FAA was limiting the flights at BALLS to 495,000 feet. It turns out that 500,000 feet is the working definition for low Earth orbit. The chances we would hit anything are pretty remote, but it helps to be sure!

As a point of reference, the highest altitude reached by an amateur rocket so far is 385,800 feet. Ky Michaelson’s team flew the GoFast rocket to that height on August 18, 2014. It was the second time an amateur rocket had reached space, officially defined as 100 km, or 328,084 feet.

The Bureau of Alcohol, Tobacco, Firearms, and Explosives (BATFE, Often Shortened to ATF)

The way the ATF and the rocketry community have interacted over the years is interesting. At times it has been very acrimonious, yet I’ve heard many stories of very reasonable interactions between the ATF and people in rocketry. As you read this section, keep in mind that this is the agency that takes point on keeping explosives out of the hands of terrorists. ATF agents have a good reason to take a close look at people who are buying things like black powder, igniters, and so forth. I really don’t envy their job. My personal view is that we should cooperate with the ATF, following all of its rules and regulations to the best of our understanding, so they don’t need to spend much time on us and can concentrate on keeping dangerous materials out of the hands of the bad guys.

The ATF regulations that cover explosives as they pertain to rocketry are largely encapsulated in 27 CFR 555. As you know from the section on the FAA, this is a document containing regulations (in this case, on explosives).

We start right off with some confusing information. Low-power rockets containing less than 62.5 grams of propellant are apparently fine as far as the ATF is concerned, because they have an explicit exception for them in 27 CFR 555.141, which lists things not considered explosives. It says:

(10) Model rocket motors that meet all of the following criteria—

(i) Consist of ammonium perchlorate composite propellant [APCP], black powder, or other similar low explosives;

(ii) Contain no more than 62.5 grams of total propellant weight; and

(iii) Are designed as single-use motors or as reload kits capable of reloading no more than 62.5 grams of propellant into a reusable motor casing.

That means the low-power motors sold in hobby stores, and many of the smaller APCP motors, are not regulated by the ATF.

According to the regulation, though, any rocket motors with more than 62.5 grams of propellant, which includes all high-power motors and a few of the larger mid-power motors, are considered explosives and are covered by ATF regulations.

While the regulations have not been updated, the situation changed in 2009, when NAR and TRA won a lawsuit against the ATF. The short version is that APCP model rocket motors of any size are no longer covered by 27 CFR 555. As far as the ATF is concerned, you can buy, transport, store, and use black powder motors with less than 62.5 grams of propellant and APCP motors of any size for use as rocket motors.

There are two other items the ATF regulates that are also used in high-power rocketry, and in this book. They are black powder for ejection charges and igniters for lighting motors and ejection charges.

The ATF allows manufacturers to bundle and sell igniters and small amounts of black powder with their motors. That makes it easy for us to get the igniters and ejection charges we need for smaller flights.

Igniters that are sold separately and the loose black powder we use for dual-deploy rockets are another matter. The ATF classifies black powder and APCP as a low explosive. While you can buy up to 50 pounds of black powder with little trouble, the ATF says this is only legal for use in antique firearms. The ATF also allows the sale of igniters for several purposes, but rocketry is not one of them. At the same time, some of the igniters used in amateur rocketry are apparently not considered igniters by the ATF, although there are no clear guidelines that tell you which are allowed and which are not.

You need a Low Explosives Users Permit (LEUP) for many kinds of loose igniters and for black powder that is used for anything except antique firearms. They must also be stored in a Class 4 safe, and the igniters and black powder must be stored in separate safes. The safes cannot be stored in a residence, but they can be kept in most attached garages. You can find all of the details on the requirements for the safes in 27 CFR 555.210.

You must be 21 years old to get a LEUP.

All of this sounds pretty onerous, and I suppose it is. There are some practical ways to satisfy the ATF without breaking the bank, though. For example, it is perfectly acceptable for one person in the club to maintain a Class 4 safe for club use. Each person is still supposed to have their own LEUP, but the ATF is fine with multiple people using a single storage facility, as long as there is a written letter of understanding in place. Another option is to stick with igniters like the Quest Q2G2 for lighting ejection charges. They work fine, and while it is always open to interpretation, these igniters do not seem to run afoul of ATF regulations, while e-matches and homemade igniters generally do.

The Department of Transportation (DOT)

I still remember one scared truck driver arriving at my door with a package he desperately wanted to get off of his truck. The box was covered with various stickers and labels that said DANGER, EXPLOSIVE, and so forth. I'm sure he wondered what sort of lunatic I was to be ordering this obviously hazardous stuff for delivery to my home.

It's the DOT that creates the regulations for shipping flammable and explosive materials. Most of our rocket motors, igniters, and black powder can only be shipped by ground. Special handling procedures are required for some quantities of material, which is why we almost always end up paying a special hazardous materials shipping fee for high-power rocket reloads.

For the most part, those of us who order rocket motors don't really need to worry about shipping regulations. Just be aware that you can't ship rocket motors yourself without getting a lot of permits and following the shipping regulations. You can't even return a motor to the sender.

You can find out more in 49 CFR 172 and 49 CFR 173, both of which are available online.

The National Fire Protection Association (NFPA)

According to its website, the NFPA is an independent organization founded in 1896 to "eliminate death, injury, property and economic loss due to fire, electrical, and related hazards." Unlike the FAA, ATF, and DOT, the NFPA is not a government agency, and is not responsible for enforcing its rules and regulations. On the other hand, because of its stature, the NFPA writes rules and recommendations that are frequently adopted into law by state or local governments.

These rules and recommendations are developed in cooperation with experts in various fields. One of its guidelines is NFPA 1127, the Code for High Power Rocketry. It’s developed in cooperation with NAR and TRA—in fact, members of both NAR and TRA serve on the NFPA Technical Committee on Pyrotechnics.

While the NFPA does not pass or enforce laws, NFPA 1127 is arguably the most important legal document for high-power rocketry in the United States. That’s because it has been adopted into law by so many state and local governments, something that is made easy by Annex C, which is a sample ordinance. All the lawmakers need to do is fill in the blanks and vote to make the ordinance the law. That’s not a bad thing for amateur rocketry, though. NFPA 1127 amounts to a careful legal description of the safety codes and practices we follow anyway. After all, NAR and TRA *did* help to write this document.

Some agencies are not covered by the NFPA. Specifically, national, state, and local governments and universities are exempt, as are licensed businesses.

Many people who fly high-power rockets also fly low-power rockets. There is a similar document for low-power rocketry called NFPA 1122, the Code for Model Rocketry. NFPA 1125 covers manufacturing of rocket motors.

You can find a copy of NFPA 1127 online, although you have to sign up with the NFPA to get one.

HIGH-POWER ROCKETRY

The NFPA defines a high-power rocket motor as any rocket motor with no more than 40,960 N-s of total impulse. That’s an O motor. It also defines a model rocket motor as any motor with no more than 160 N-s of total impulse (a G motor) and an average thrust no greater than 80 N. That last point is rather interesting. While most rocketeers consider the AeroTech G104T, with a total impulse of 90 N-s, to be a mid-power motor, according to NFPA 1127 it’s a high-power motor.

The NFPA also defines a separate category of motor called the hybrid motor. We’ll look at this a bit more carefully later, but according to the NFPA, a hybrid motor is one that has the fuel and oxidizer in different physical states. The most common hybrid motor in amateur rocketry uses nitrous oxide as an oxidizer, and some form of high carbon fuel, such as rubber or paraffin.

The NFPA definition of a high-power rocket parallels the FAA and industry definition, with one exception. It’s a high-power rocket if it is powered by a high-power motor, has more than 125 g of propellant, or weighs more than 1.5 kg. The exception is for *complex rockets*, which are rockets containing more than one motor, either staged or clustered. According to NFPA 1127, as long as all of the individual motors have less than 160 N-s of total impulse, the rocket can have a grand total of up to 320 N-s of total impulse and still be classified as a model rocket rather than a high-power rocket.

While there is no weight limit for a model rocket, the NFPA does put a limit on thrust-to-weight ratio, stating that the average thrust of the motors at launch must be at least three times the weight of the rocket. That’s really quite lenient. With a thrust three times the weight of the rocket, the acceleration would be twice the acceleration of gravity, or about 19.6 m/s^2. A rocket needs to reach a decent speed for the fins to keep it stable as it travels through the air; most sources say the speed should be at least 30 mph, which is about 13.4 m/s. With some basic physics, we find out that the time needed to reach that speed with a thrust-to-weight ratio of 3 is:

$$v = at$$

$$t = \frac{v}{a}$$

$$t = \frac{13.4}{19.6}$$

$$t = 0.68\ \mathrm{s}$$

With the time and acceleration known, we can find the minimum length of the launch rail needed for this thrust-to-weight ratio:

$$d = \frac{1}{2} a t^2$$

$$d = \frac{1}{2} 19.6 (0.68)^2$$

$$d = 4.5\text{m}$$

Four and a half meters is nearly 15 feet. Most launch rods for high-power rockets are 6 to 8 feet long, although there are certainly longer ones.

Working backwards, we can find the thrust-to-weight ratio needed for a common 6-foot rail, which is about 1.8 meters long:

$$d = \frac{1}{2} a t^2$$

$$d = \frac{1}{2} \frac{v}{t} t^2$$

$$d = \frac{1}{2} v t$$

$$t = \frac{2d}{v}$$

$$t = \frac{2 \times 1.8}{13.4}$$

$$t = 0.27\text{s}$$

$$a = \frac{v}{t}$$

$$a = \frac{13.4}{0.27}$$

$$a = 49.6\text{m}s^2$$

That’s a shade over 5 gravities, so we need a thrust-to-weight ratio of about 6 for a 6-foot rail. It’s nice that the NFPA gives us the option to use a lower value, but don’t use it for planning purposes! Of course, you should be simulating all of your flights anyway, and one of the things the simulation will tell you is the speed off of the launch rail.

LAUNCH SITE AND OPERATIONS

One of the more important things that the NFPA does is define safety measures, minimum launch distances, and the role of the Range Safety Officer (RSO). These are codified in the NAR and TRA safety codes, but the local laws that adopt NFPA 1127 make these definitions and distances legal requirements in many areas.

The RSO has been in charge of safety at both professional and amateur launches since the very early days of rocketry. NFPA 1127 says the RSO must have knowledge of NFPA 1127 and technical competence in rocketry. The RSO’s responsibilities start with laying out the launch site. There are common sense definitions for several specific areas, including the launch site parking area, the launch area, the prepping area, the recovery area, and the spectator area. The RSO has the authority to stop a launch if, “in his or her judgment, a potential or actual danger, accident, or unsafe condition exists.” The RSO is also responsible for doing a preflight inspection on all high-power rockets to make sure they follow the safety guidelines in NFPA 1127.

The launch site must also have some equipment on hand, including fire extinguishers, a first-aid kit, and a way to communicate with everyone at the launch site (see Figure 11-1).

Those safety guidelines are scattered throughout this book. They include not modifying the rocket motor or using it for something other than the intended purpose. Rockets must be built from paper, wood, rubber, plastic, fiberglass, or ductile metal. The RSO can ask for proof that the rocket is stable in the form of simulations that show the center of pressure and center of gravity.

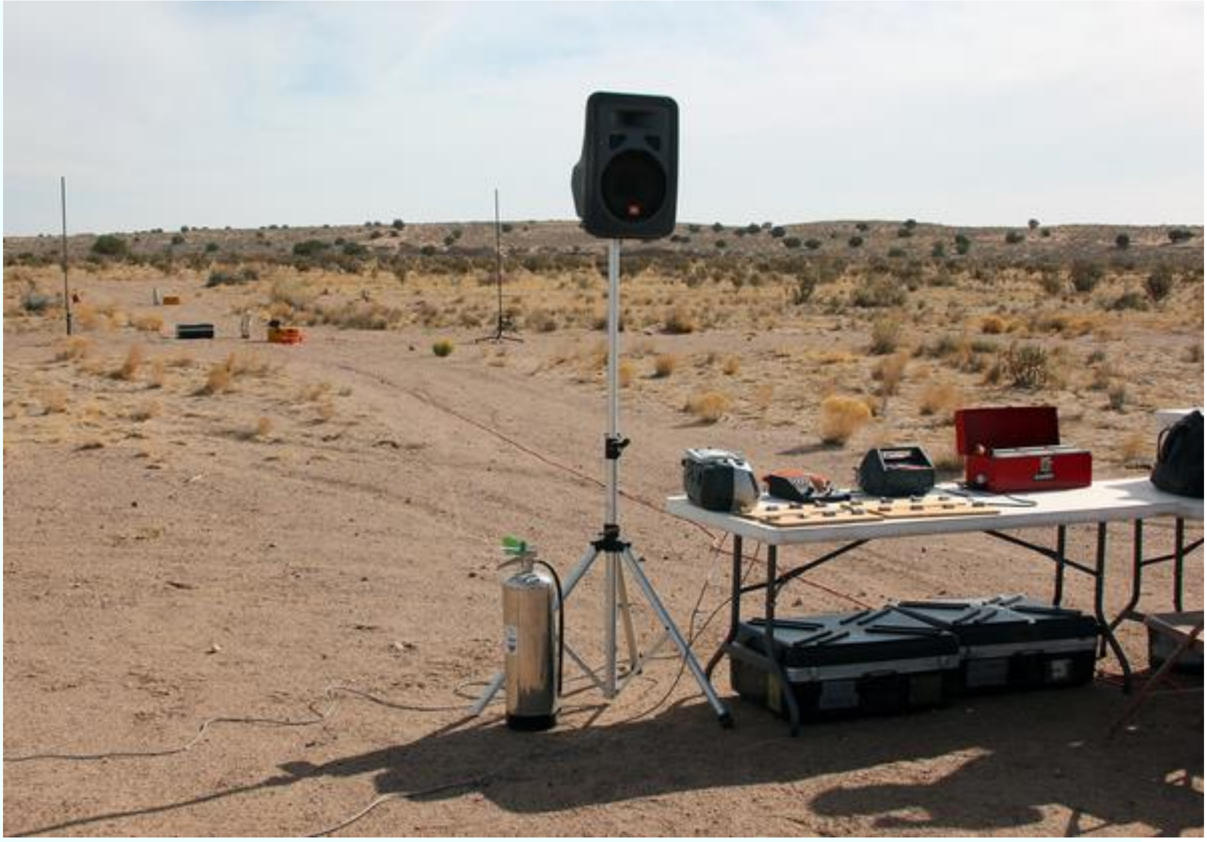


Figure 11-1. Here you clearly see two of the three required items at the launch site. Fire extinguishers are placed near the pads, power supply, and launch table. The black speaker on the pole is the PA system.

It should go without saying, but the NFPA spells it out: you may not fly a rocket when consuming alcohol or any drugs that would inhibit judgment.

The RSO always has the final say on safety. If the RSO makes the decision that a rocket cannot be flown, that decision is final. There is no appeal. The flier can either make any changes the RSO has specified or go home.

That said, the RSO is not responsible for your rocket. The flyer is ultimately responsible for making sure the rocket is built and prepared for flight properly; likewise, the flyer is responsible for any damage caused by the rocket. An RSO inspection is intended as a way of catching serious problems, not to transfer responsibility.

LAUNCHERS

The NFPA lays out specific requirements for high-power launchers. These requirements include:

1. The launcher must be stable, and provide guidance until the rocket is traveling fast enough to be stable. Most sources put the minimum speed at 30 mph, although the NFPA does not specify the speed.
2. A blast deflector plate is required if the rocket exhaust would otherwise hit flammable material.
3. The rocket must be launched within 20 degrees from vertical. Note that this is different from low-power rockets, which can be tilted up to 30 degrees from vertical. Exceptions for rocket planes can be found in other regulations.
4. The launcher must use an electrical ignition system with a switch that returns to the off position when released.
5. There must be a safety interlock key.
6. The launcher must launch the rocket within 3 seconds from pressing the launch button.
7. For cluster rockets, the system must be tested to ensure that all igniters will fire within 1 second of pressing the launch button.
8. Igniters cannot be installed in the motor until it is in the launch preparation area or at the launcher. The rocket must be pointed away from spectators after the igniter is installed. Most RSOs will reasonably insist that the igniter be installed after the rocket is on the launch rail and pointed up, although the NFPA does not go quite that far.
9. Firing circuits and onboard pyrotechnics must be disabled until the rocket is in flight position. If the rocket needs to be removed from flying position, either to cancel the launch or for adjustment, the firing circuit and onboard pyrotechnics must be disabled first.

STORING ROCKET MOTORS AND OTHER EXPLOSIVES

You may recall that the ATF has very specific storage requirements for low explosives, and that black powder and igniters are both covered by those requirements. Black powder rocket motors with less than 62.5 grams of propellant and APCP rocket motors are both exempt from those requirements, as is black powder if it is used for antique firearms—but not if it is intended for use in rockets.

NFPA 1127 also has storage requirements for regulated materials, which include high-power rocket motor reloads other than APCP motors and pyrotechnic modules. While no specific definition is given, pyrotechnic modules presumably refers to igniters and black powder. The storage requirements conform to the requirements in 27 CRF 555. Here are the general requirements:

1. Store all high-power motors, reload kits, and pyrotechnics at least 25 feet from smoking, open flames, or other sources of heat.
2. Store no more than 50 pounds of explosives, to include the propellant weight of motors and any black powder.
3. Use a Type 2 or 4 indoor storage magazine (Figure 11-2), as defined in 27 CFR 555. See that regulation for specifics. The box is made from 2”-thick hardwood covered in metal, 12-gauge steel with a non-sparking interior covering, or masonry. The hinges must be installed so they cannot be removed without opening the box, and the box itself must be locked with two locks. Several kinds of locks are allowed, but all are pretty sturdy.
4. The storage magazine must be painted red, with “EXPLOSIVES – KEEP FIRE AWAY” painted in 3” tall white letters on the top of the box.
5. The magazine cannot be located in a residence, although it can be in a detached garage or outbuilding. With approval from the ATF, presumably in the form of a LEUP, the magazine can also be stored in the attached garage of a single-family residence.

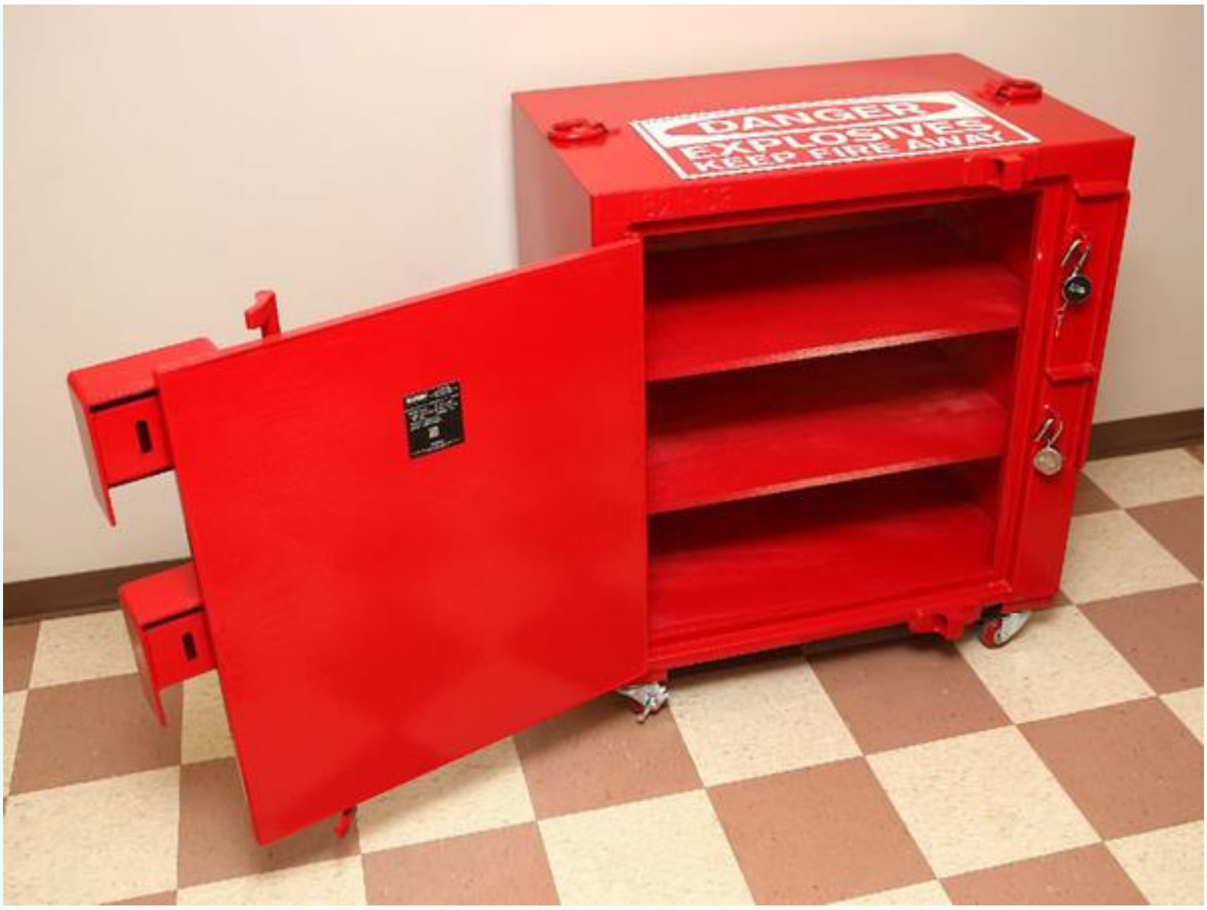


Figure 11-2. An indoor storage magazine for low explosives. Photo courtesy of Armag Corporation, www.armagcorp.com.

When you choose a location, keep in mind that black powder motors are known to react poorly to *thermal cycling*, or repeated swings in temperature. Storing black powder motors in a garage expose them to thermal cycling, as the temperature swings during the day and as the seasons change. The problem can cause them to undergo a catastrophic failure, or CATO, when you use them in a rocket. This occurs because the black powder, cardboard tubes, and nozzle all have different coefficients of expansion. Thermal cycling can create a crack between the materials, allowing the motor to burn erratically.

Thermal cycling does not seem to be an issue with APCP motors. Also, assuming it is a reload, you can always inspect the fuel grains before use. Pay special attention to the joint between the fuel and the paper outer lining, making sure there are no gaps.

Breaking all of this down, you have some choices. Because of the lawsuit with the ATF that reclassified APCP motors, you no longer have to store them in an explosives magazine, nor do you have to store less than 50 pounds of black powder motors in any special way. You are only required to have one of these storage containers if you are storing black powder for use in something other than an antique firearm, or if you are storing some kinds of igniters. That does not mean it is a bad idea to use a quality explosives container, simply that it is no longer required by federal law or laws based on NFPA 1127.

If you do decide to build an explosives magazine, and place it in a garage, outbuilding, or some other location where temperature is not controlled, you should be fine storing loose black powder, igniters, and APCP motors. Black powder motors should be stored in a temperature-controlled area, though.

The National Association of Rocketry (NAR) and the Tripoli Rocketry Association (TRA)

You might have noticed that none of the regulations we've discussed so far even mention getting certified to fly high-power rockets, but you know that you do have to get certified to fly them. Why?

Amateur rocketry is a self-regulating hobby. The two big players in the United States are NAR and TRA. These organizations have been very successful at keeping regulations that govern rocketry fairly uniform across the country, and keeping the restrictions that exist reasonable in most cases. Certification for high-power rocketry is one of the ways they do this. There are no federal regulations that say you have to be certified to build and fly high-power rockets.

NFPA 1127 gives a passing mention of certification, saying that:

5.4.1 Certification of a user shall require both of the following: (1) Proof that the user is at least 18 years old (2) Proof that the user possesses a level of knowledge and competence in handling, storing, and using a high-power solid-propellant rocket motor and high-power rockets that is acceptable to the certifying organization

This means state and local ordinances based on NFPA 1127 at least mention certification, but the details are largely left to the certifying organization.

Both organizations also take another carrot-and-stick approach to keeping rocketry safe. They each offer insurance to individual members and clubs, but only if their rules are followed. You can find details on the respective websites, but it boils down to following the safety code, including making sure people are certified when appropriate.

The NAR and TRA safety codes for high-power rocketry are included in Appendix B, and can also be found on their respective websites. Expect to see several questions based on the safety codes, especially questions about launch rod angles (no more than 20 degrees from vertical), maximum wind speeds (no more than 20 miles per hour), and safe distances, in the Level 2 exam.

Motor Construction

For the most part, we buy our rocket motors based on size, cost, and performance characteristics, without worrying too much about how they are made. Let’s figuratively open up the rocket motors we use and take a look inside to see what makes them tick.

You should not actually disassemble a rocket motor, especially a black powder rocket motor. Model rocketry has a wonderful safety record when model rocket motors are used as designed. Some of the blemishes on our safety record come from idiots who have have disassembled rocket motors. One individual tried to cut a black powder motor open with a power tool; another dumped the contents into a cup and lit them with a match. On average, about once a year someone in the United States makes a trip to the emergency room with burns from a model rocket motor. In all of the cases where I know of the particulars, they were violating the safety standard, usually by tampering with a motor. Don’t become one of those statistics.

While there are a lot of different fuel characteristics to consider when designing a rocket motor, two jump out as the leading factors for the parts of the design we’ll look at here. The first is *burn rate*, and the second is *specific impulse*.

Burn rate is the speed at which the propellant burns. Burn rate depends on a lot of variables besides the composition of the fuel, such as the pressure, but to oversimplify a bit, imagine lighting one end of a cylinder of rocket fuel that is treated or contained so the sides will not burn. The burn rate is the velocity of the burning area, or the length of the rod divided by the time it takes to burn from one end to the other.

Specific impulse gives a way to measure the relative power of rocket fuels. You are already familiar with the term impulse, which is the force exerted by the motor, also called the thrust. You also know that we classify rocket motors by total impulse, which is the integral of the impulse over time. Specific impulse is the impulse per unit of fuel consumed. While there are a couple of competing definitions, the one most commonly used in amateur rocketry is the total impulse generated divided by the weight of the fuel. The usual units of total impulse are newton-seconds, and the unit for weight in the metric system is the newton, so the usual unit for specific impulse is the second. While there are certainly other factors to consider, all other things being equal, a higher specific impulse means the rocket fuel is more efficient.

There are three common rocket fuels used in amateur rocketry today. The first is black powder, which is used extensively in low-power rocketry. Most motors up to about E power are black powder motors, and some larger ones are, too. Black powder is a mixture of potassium nitrate, charcoal, sulfur, and a binding agent to create a solid so the fuel doesn’t pour out of the nozzle of the rocket. Black powder rocket motors have a fast burn rate compared to other commonly used fuels, and they have a specific impulse in the neighborhood of 80 seconds.

The second common type of rocket fuel is ammonium perchlorate composite propellant, abbreviated as APCP or sometimes just AP. Ammonium perchlorate, NH_4ClO_4, is actually the oxidizer; the fuel is the binder and various metals mixed with the oxidizer and binder. This is the fuel used in almost all high-power motors and most of the mid-power motors. It’s also the fuel used for the solid rocket boosters on the Space Shuttle. APCP rocket fuel is frequently modified to get the different effects you see at the launch site: adding titanium sponge to produce sparks; reducing the oxidizer to get thick black smoke; or adding various chemicals to get blue, green or red flames. AP burns slower than black powder but has a specific impulse of 180–260 seconds, depending on the precise fuel formula and the design of the motor.

The third common type of fuel is used in an entirely different kind of rocket motor, called a *hybrid rocket motor*. Hybrid motors use a fuel and oxidizer that are in a different state. By far the most common design uses nitrous oxide (N_2O) for the oxidizer and some form of solid hydrocarbon, such as paraffin or rubber, as the fuel. With a specific impulse of 250 seconds or so, hybrid rockets perform well. Unlike solid rockets, they are also easy to throttle, so the thrust can be varied during flight. The downside of hybrids is that they are far more complex to set up and use than solid rockets, although they are much simpler than rockets that use both a liquid oxidizer and fuel. The cost per flight is generally fairly low, but the initial cost to buy the ground support equipment can be daunting. Fortunately, many clubs have the ground support equipment, which is available for use by club members.

There are a few extra safety issues with handling nitrous oxide, too. The nitrous oxide tank is a high-pressure tank, about 750 psi at normal temperatures, which requires some special handling precautions. Nitrous oxide is a liquid in the tank, turning to a gas as it expands in the chamber. The gas is generally allowed to vent from the rocket to prevent pressure buildup, and can get quite cold. At atmospheric pressure it boils at about –127 degrees Fahrenheit, plenty cold enough to freeze your skin. It also turns into a supercritical fluid at 97 degrees Fahrenheit, further complicating handling on hot days. We’ll cover hybrid rocket motors in more detail in *Make: Advanced High-Power Rockets*.

There is one simple concept you need to grasp to understand the rest of the information about motors. The thrust of the rocket is proportional to the pressure inside the chamber, which is in turn proportional to the area of fuel that is burning. One way to get more thrust from a solid-propellant rocket is to increate the area of the propellant that is burning.

Lets go back to the solid-propellant motors and see what’s inside.

Figure 11-3 shows a typical black powder motor like the ones used in low-power rocketry. The igniter lights the black powder, which burns outwards in a roughly spherical shape, stopping when it gets to the nozzle or casing. Once the burn surface hits the casing, the thrust drops off a bit, since the burn area is roughly the area across the inside of the chamber.

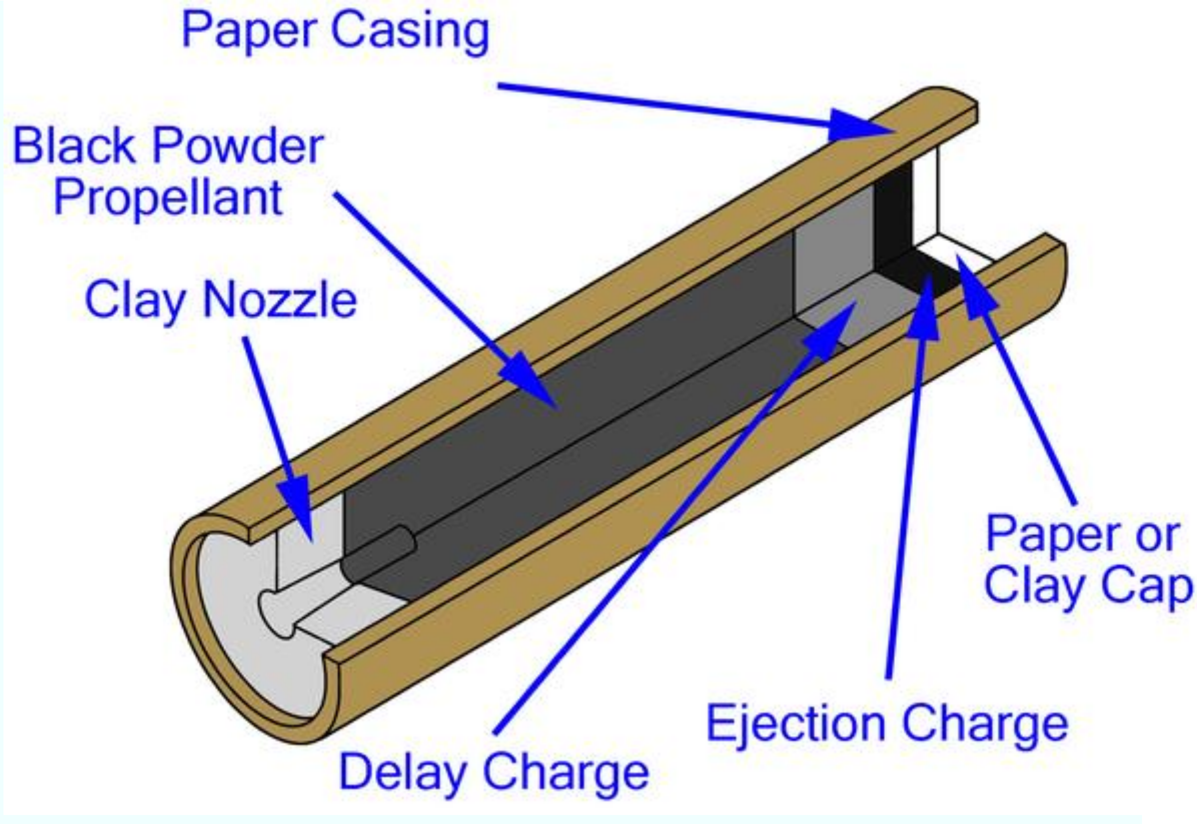


Figure 11-3. Cutaway view of a typical black powder motor.

The Estes C6-5 is a typical black powder motor. Its thrust curve is shown in Figure 11-5. You can clearly see the early spike in thrust as the motor burns out in a spherical shape, followed by the long plateau as the motor burns from the bottom to the top of the propellant.

APCP has a higher specific impulse than black powder, but it actually burns slower. It burns slow enough that an end burner doesn’t present enough surface area to generate sufficient thrust for most uses. One way to solve this problem is to build a core burner, like the one shown in Figure 11-4.

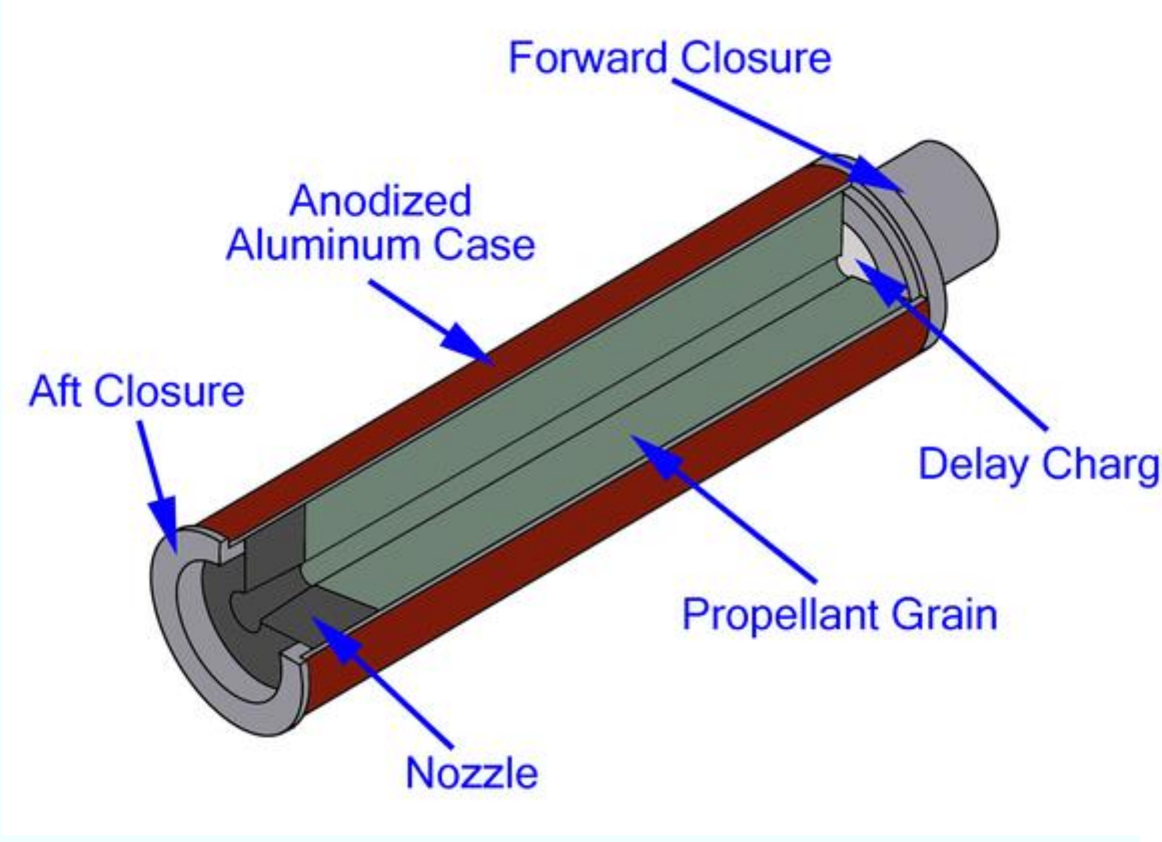


Figure 11-4. A typical core burning high-power motor.

A motor like this is easy to manufacture and solves the problem of presenting more surface area right away, giving a higher initial thrust than an end burner. As the motor burns, the inner cylinder expands, gradually increasing the surface area. This gives a progressive thrust curve. Of the three basic shapes for a thrust curve shown in Figure 11-6, this is usually the least desirable, since it gives a slow takeoff speed. Most motors are designed for a neutral thrust curve, although a few are regressive.

You have seen that most high-power motors have several individual grains, each of which is a core burner. This configuration is called a Bates grain. The grains burn through the central core and at the top and bottom of each grain. When properly proportioned, a Bates grain will burn within about 3% of a perfect neutral thrust curve. The disadvantage of a Bates grain is that it allows burning at the edge of the motor case right away, where a classic core burner uses the fuel itself as an insulator until the fuel is nearly exhausted.

Note that a Bates grain design requires the fuel between grains to burn, so there needs to be a small gap between the fuel grains (see Figure 11-7). That’s why the fuel grains in your motors seem a bit loose, moving back and forth when you shake the motor after the motor is ready for flight. That movement is critical, allowing the area at the top and bottom of the grains to light. Larger motors sometimes even have O-rings between the grains to ensure proper initial spacing.

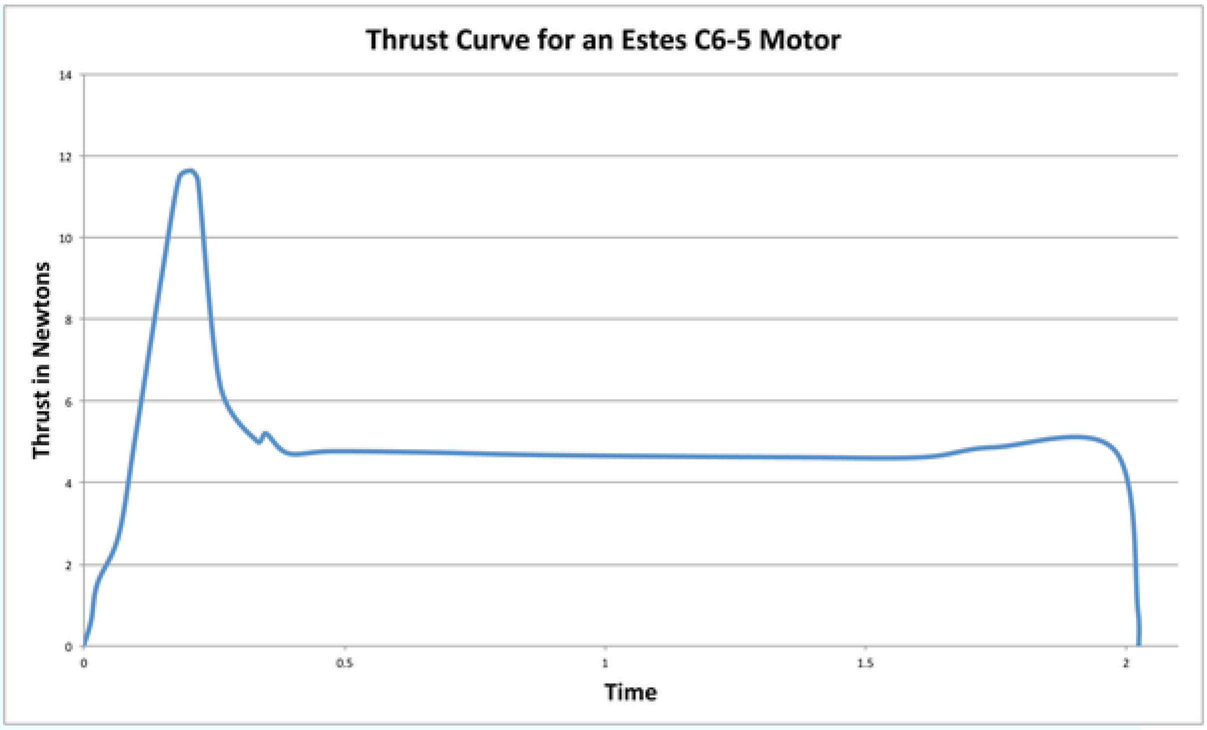


Figure 11-5. The thrust curve for the Estes C6-5.

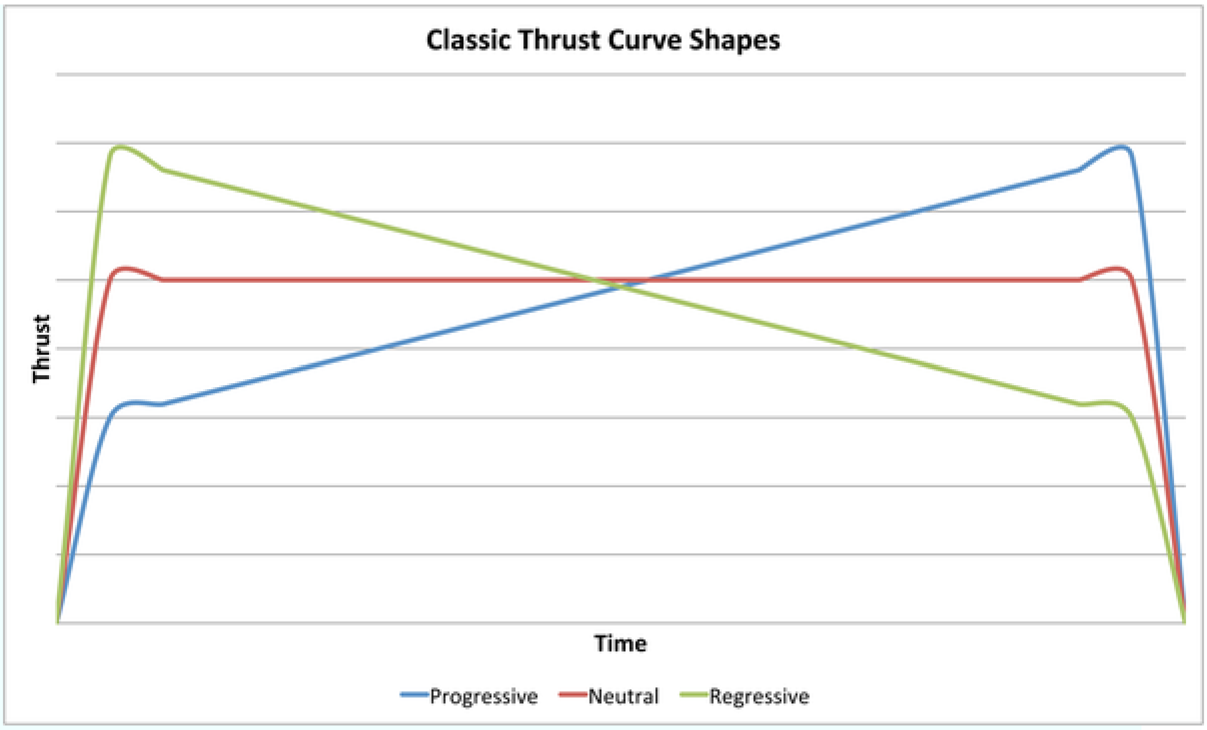


Figure 11-6. Thrust curves are classed as progressive, neutral, and regressive.

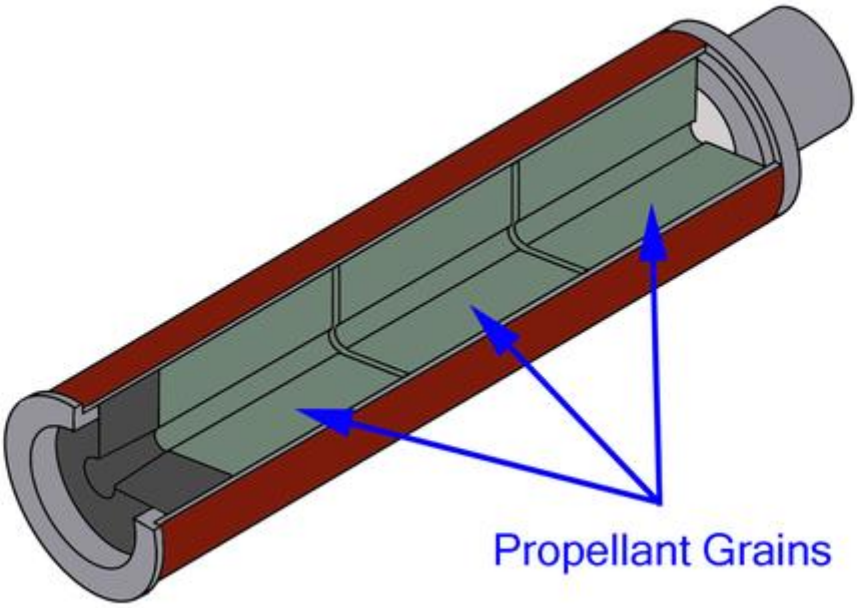


Figure 11-7. A core burner with the grains cut so the ends can burn, giving a neutral thrust curve, is called a Bates grain.

There are a huge number of other grain configurations. Figure 11-8 shows a few of them from the end of the grain. The C slot is seen on a lot of mid-power and some small high-power APCP motors. It gives a fairly flat thrust curve without the need for a Bates grain, but still exposes the insulation at the edge of the case to the heat and pressure of the rocket motor for the entire burn time. The moon burner also gives a fairly flat thrust curve, but doesn’t expose the motor case insulator to the burning propellant for the entire burn. The star configuration has a lot of variants, sometimes using slits for the rays of the star, putting cores at the ends of the slits, and so forth. Star grains and their variants can be designed to give progressive, regressive, or neutral thrust curves, and even to have multiple times when the thrust spikes. The downside is that they are harder to design and manufacture.

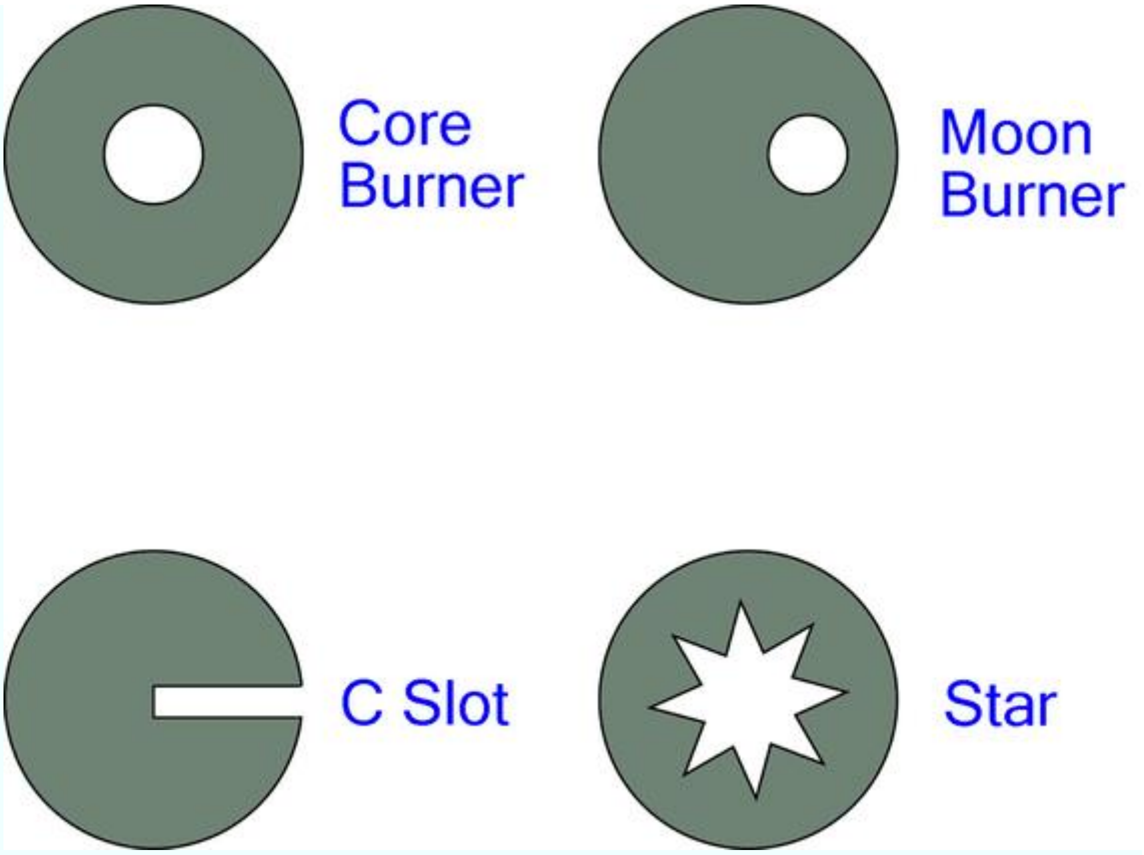


Figure 11-8. Some common grain configurations. The core-burning Bates grain configuration is the most common in high-power APCP motors, with the C-slot grain finding frequent use in low- and mid-power APCP motors.

The BATES Grain

BATES was originally an acronym for BAllistic Test and Evaluation System, a method for testing rocket fuel developed at the Air Force Research Laboratory. The original method used a single fuel grain that was inhibited on the outside, just as most modern fuel grains use a paper outer wrap to keep the fuel from burning along the outside right away. Gradually the name was applied to the fuel geometry described here, where multiple grains are cut to allow end burning so the overall motor thrust curve is neutral or very close to neutral.

These days, Bates is usually seen with an uppercase initial letter and all other letters lowercase, probably because it looks like a person’s name. We’ll stick to that convention.

Igniters

Igniters come in a wide variety of shapes and characteristics. Figure 11-9 shows some common igniters used in low- and high-power rocketry.

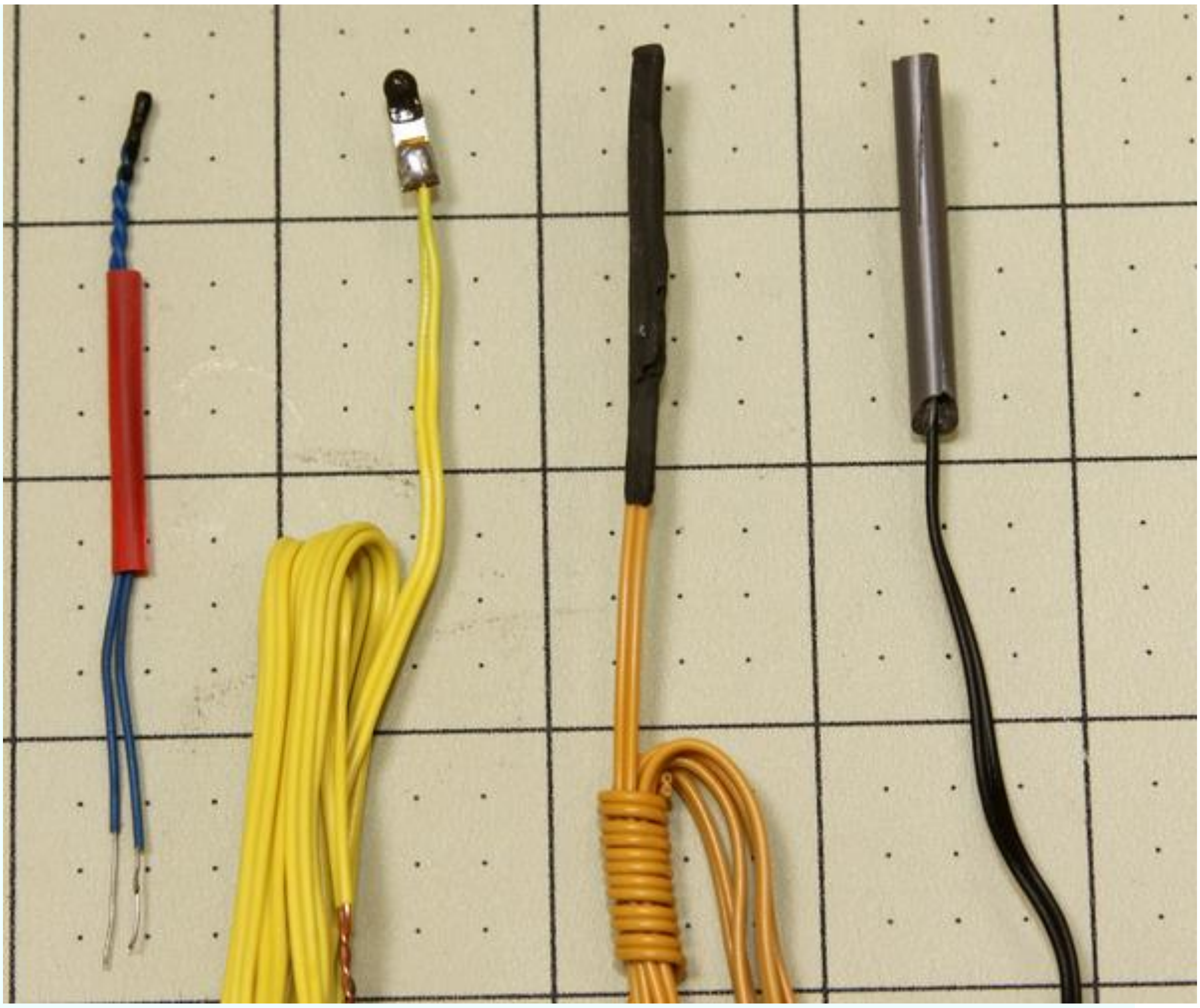


Figure 11-9. Some representative igniters. From left to right, the Quest Q2G2, an e-match, an AeroTech First Fire Starter, and a typical igniter for a large motor.

The Quest igniters are commonly used to light low-power rocket motors, but they also work for lighting ejection charges on high-power rockets. These are a personal favorite. They are readily available by mail order, are not regulated by the ATF, and light easily. The disadvantage is the short lead wires, which frequently means you need to solder longer lead wires to the igniter. You can occasionally find them with longer lead wires. Another popular igniter for ejection charges is the electric match, or *e-match*. These are a lot harder to find, and some kinds are regulated as explosives by the ATF. Suppliers come and go quickly, and they are harder to find by mail order. Check with your local club members. You may be able to buy a few spares from them, or they can tell you the best current source for e-matches.

Most rocket motors come with an igniter, although it’s a good idea to pick up some spares. APCP is actually fairly hard stuff to light. AeroTech motors solve this problem by using a large chunk of flammable material at the end of the igniter. CTI takes a different approach. Most of their motors have a small black powder pellet embedded in the top fuel grain. This lights easily with an e-match, and in turn lights the APCP.

If there are some old timers in your club, you may also run across someone using a flash bulb as an igniter, either for a motor or an ejection charge. These work great, but have gradually vanished as commercial igniters have become more common and as flash bulbs faded while strobe flashes took over in cameras.

By now you are accustomed to continuity checks. You do a continuity check at the launcher to make sure the connections to the motor igniter are good, and you listen for beeps from altimeters to make sure the ejection charge igniters are connected. There is a potential problem with these continuity checks, though. Some igniters, such as the nichrome wire Estes igniter, require a fairly high ignition current, while others, like the Quest Q2G2, low-current e-matches, and flash bulbs light with a very low current. That’s not usually a problem, since altimeters and high-power launchers are designed to deal with either. Some low-power launchers are designed specifically for high-current igniters, though. They can light a low-current igniter while doing the continuity check! If in doubt, always check the ignition system you are using with a spare igniter to make sure the ignition system will not light the igniter with just the continuity check, and that it will light the igniter reliably when the launch button is pressed.

Clustering Motors

Clustering is a topic we’ll return to in *Make: Advanced High-Power Rockets*. There are some test questions about clustering igniters, though, so we’ll briefly discuss the issues here.

Cluster rockets are designed to light two or more motors at the same time. This presents a fairly interesting problem from an electronics standpoint. In a perfect system, the igniters would have exactly the same resistance, draw exactly the same current, and light at exactly the same time. In that case, you could orient the igniters in series or in parallel. The multiple igniters would light at the same time.

In the real world, there is always some slight imbalance. The conventional wisdom with igniters is to wire clustered igniters in parallel. If one igniter lights early, the igniter will heat up, raising its resistance and thus pumping more current through the other igniter. Eventually, the first igniter to light will burn through, and all of the current will go into the slower igniter.

There are a few kinds of e-matches that burn so hot they form a plasma. This plasma actually reduces the resistance to current flow, sucking current away from any igniter that has not already lit. These igniters need to be wired in series.

The general recommendation is to wire igniters in parallel unless the manufacturer says to wire them in series.

Even better is to conduct several tests, filming the igniters with a high-speed camera to make sure the launch system will light the igniters reliably. Another alternative is to use a redundant ignition system for each motor.

It’s generally not a good idea to mix black powder and APCP motors when clustering motors. Black powder motors light considerably faster than APCP motors, so even if the igniters all light at the same time, the rocket is likely to lift off under power from the black powder motors, ripping the igniters from the APCP motors. If you do decide to mix the types of motors, consider using an independent electrical ignition that stays with the rocket. This should be triggered by the normal ignition system, and should abort if current from the normal ignition system is cut before the rocket is in motion. Anything else would be unsafe. Light the APCP motors a bit before the black powder motors. The difference in time will depend on the specific motors used, so you will need to conduct timing tests using just the black powder motors and just the APCP motors to get it right.

Finally, make sure the launcher has enough current to light multiple igniters. Most high-power launchers use 12-volt ignition systems based on a lead-acid battery. This sort of battery works well for multiple igniters, but some launcher designs rob the ignition circuit of current, lowering the number of igniters it can light. Long wires, especially long thin wires, can draw enough current to make ignition unreliable. For that reason, most high-power launchers place the battery close to the launcher, using a long wire to switch the current on and off. There are several ways to switch the power on and off near the launch site. Relays tend to draw less current. Again, if in doubt, test the igniters with the actual launch control system the way it will be configured for launch to make sure they ignite reliably.

Testing Rocket Stability

You learned the basics of how to build a stable rocket back in Chapter 2, where we used a rocket simulator to make sure the center of pressure was at least one body tube diameter behind the center of gravity. Short of a wind tunnel or flight test, this is the best way to check the stability of a rocket. There are a couple of other ways to check stability, though, and they do show up on the NAR exam.

The first method for testing stability is the string test, where a string is tied around the center of gravity of a rocket, and the rocket is swung in a circle (see Figure 11-10). If the rocket stays pointed in the direction of flight, it is stable. The string test is pretty conservative, though. If the rocket tumbles, it might still be stable.

While sound in theory, this method of testing stability is obviously impractical on high-power rockets because of their size.

All of the other methods except using a wind tunnel depend on finding the center of gravity and center of pressure. You already know how to find the center of gravity.

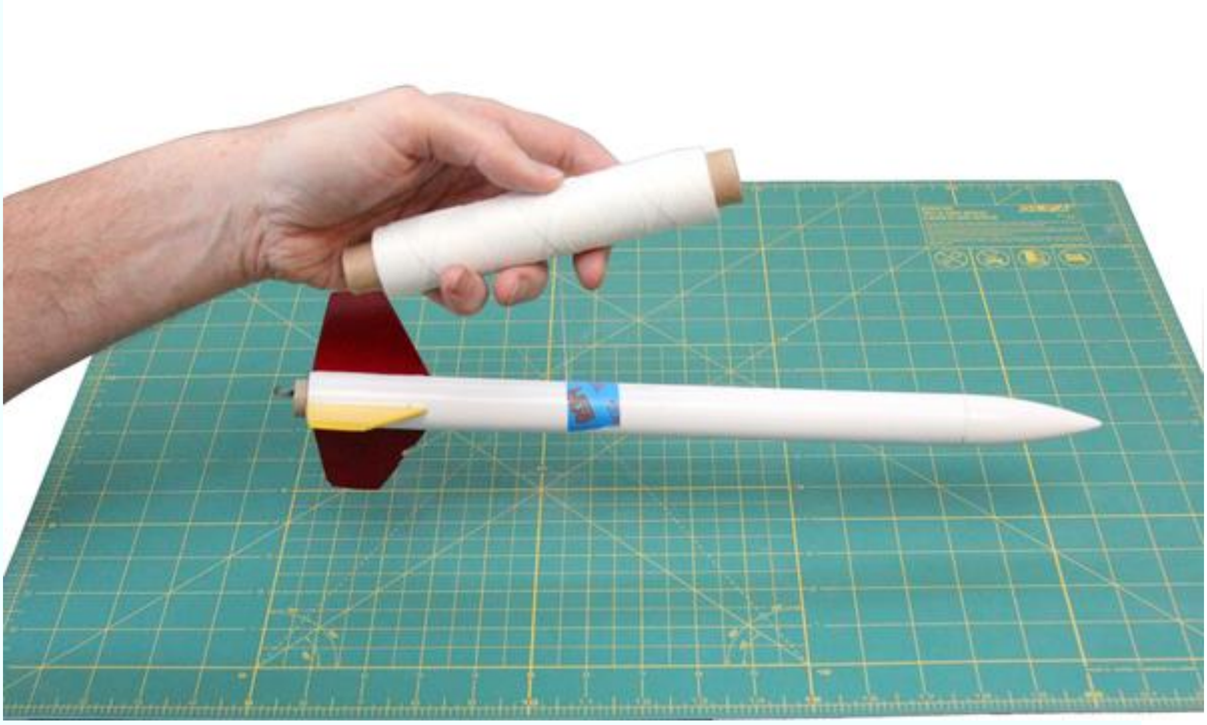


Figure 11-10. Juno, a low-power rocket from Make: Rockets, is balancing on a string. The balance point is the center of gravity. The rocket is stable if the nose remains pointed forward as the rocket swings around in a circle.

The center of pressure is harder to determine. You can find the approximate center of pressure using the cutout method (see Figure 11-11). Cut a silhouette of the rocket from a stiff material and find the center of gravity of the cutout. This is the approximate center of pressure. Like the string method, this test is conservative. If the center of gravity is at least one body tube diameter ahead of the center of pressure, the rocket is stable, but a rocket that fails this test is not necessarily unstable.

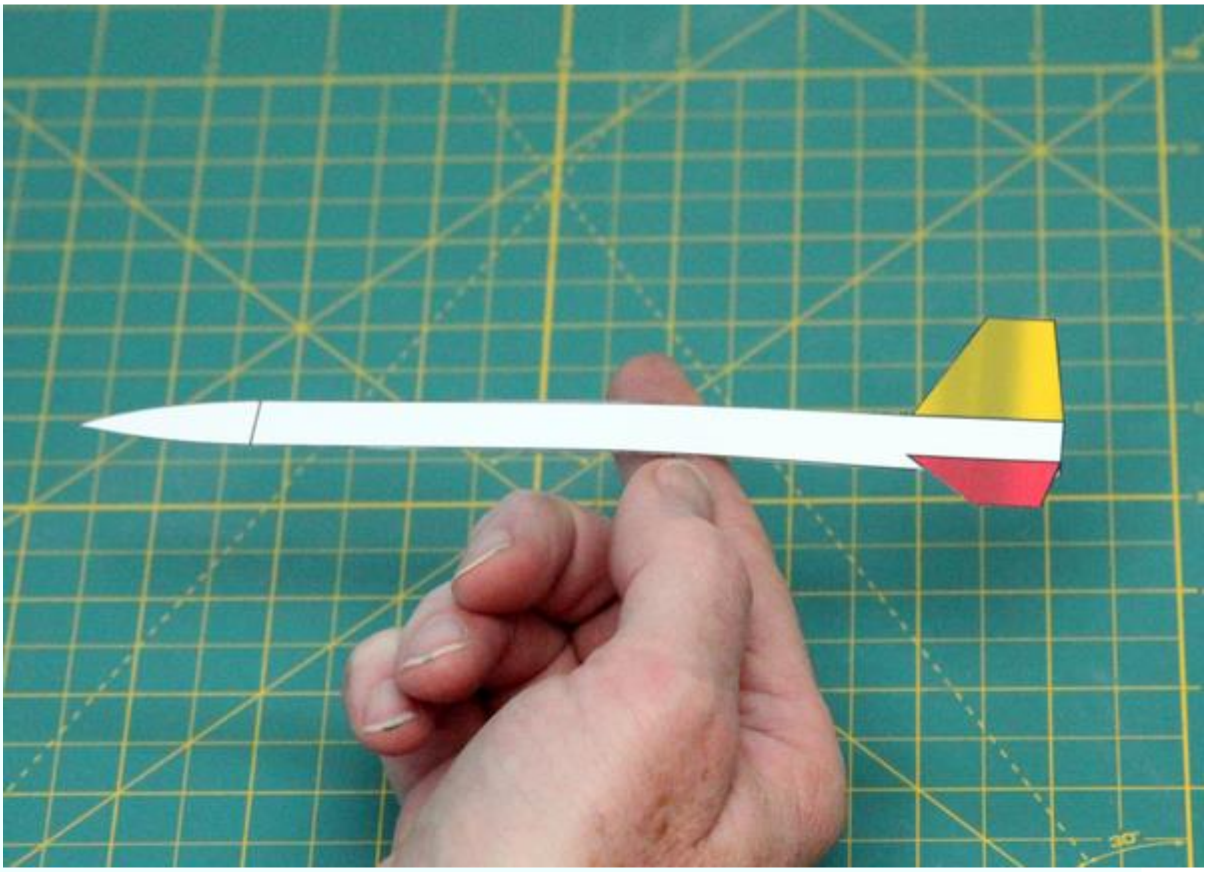


Figure 11-11. The cutout method is a way to find the approximate center of pressure of a rocket. Cut out a silhouette of the rocket from a stiff material and balance the cutout. The balance point is the approximate center of pressure.

The best way to find the center of pressure for a rocket is to use the Barrowman equations. This is a mathematical method developed by James and Judith Barrowman. It won in the research paper category of NAR's national competition in 1966, and is probably the best-known and most widely used amateur contribution to the field of rocketry. You can find the original paper online, as well as a number of tutorials and summaries of the method. *Make: Rockets* explores the method in detail, along with examples.

The Barrowman equations are used by most modern model rocket simulators, including RockSim and OpenRocket. You should be using a rocket simulator before every high-power rocket flight anyway, and the simulator shows you the result of this stability calculation. That makes all of the other methods we've discussed moot.

I mentioned wind tunnel testing at the start of this section. This is by far the best method for testing stability. Even the Barrowman equations have limitations, particularly for short, fat rockets, oddly shaped rockets, or supersonic rockets. A wind tunnel works just as well as flying the rocket for testing stability. Actually, it works better in some ways, since it allows testing at odd angles of attack. Unfortunately, most of us do not have access to a wind tunnel. If you do, though, take advantage of it.

Finally, computer simulation is advancing by leaps and bounds. It’s staggering to realize that an iPhone has more processing power than the legendary Cray 1 supercomputer. In fact, it is nearly 1,000 times faster!Among other things, *computational fluid dynamics* (CFD) is a method for simulating the way air flows past a rocket in flight. While few people have used CFD for rocket stability calculations, it is sound in theory. This method should eventually take over as computers get even faster and modern CFD codes get easier to use.

The Level 2 Test

You are just about ready for the Level 2 test. Be sure to review Appendix B. After that, take the practice test.

You can find both the NAR practice test and the TRA exam pool online. Download the test guide for the agency you will test with.

Take the test. Yes, the whole thing. This is 2–3 times the number of questions you will have to answer on the actual test, depending on the agency you decide to join. After taking the test, score yourself. Go back and review any questions you missed.

If you scored below 90%, wait at least a day and retake the test. Repeat this process, taking the test, grading it, and reviewing any missed answers, until you are confident you can pass the shorter actual test.

At this point, you are more than prepared to sail through the test with ease.

NOTE

Websites are occasionally updated, so these links may become outdated. If so, search for the Level 2 test for the appropriate organization.

Chapter 12. The Level 3 Certification Process

Getting your Level 3 certification takes more planning and time than the first two certifications. It involves creating a detailed engineering package for your flight, getting it approved, and documenting the construction of your rocket. A senior member of NAR or TRA will review and approve your engineering document, and a second member must sign off on the flight. The process is slightly different for NAR and TRA, although there are a lot more similarities than differences.

This chapter covers the certification for both NAR and TRA. A few of the steps are required for one but not the other; however, none are a bad idea no matter which agency you intend to use. Once you’ve read the chapter to get an overall idea of how to get your certification you can fine-tune the process by visiting the NAR or TRA website.

Prerequisites

You must have your Level 2 certification before attempting a Level 3 certification. In addition, you must have successfully completed at least one Level 2 flight that used electronic deployment of the recovery system.

Project Requirements

Every engineering project should start by establishing the requirements. This seems simple and obvious, yet it turns out to be an often-neglected step. For example, twice this year I have seen people struggling with their Level 3 certifications, trying to figure out how to keep a rocket they have already built from exceeding the local altitude waiver! It’s fair to say the important step of establishing requirements was skipped. So let’s start by looking at the base requirements for your Level 3 project:

- You must build a rocket that uses a single M or larger motor. Clustered or staged rockets are not allowed for the Level 3 certification flight.
- The rocket must be a relatively standard, normal-looking rocket. That means a basic body tube, nose cone, and fin set.
- The rocket must use electronic deployment with redundant systems. There must be redundant power sources for flight computers, arming switches, the computer itself, and igniters used for the deployment charges. You may use a motor ejection charge as a backup, but two computers, as you saw in Chapter 7, is the more common choice.
- The rocket must stay within the FAA waiver for the flying site. You probably know the altitude limit for your flying site by now, but do you know the horizontal distance? If your rocket goes above the altitude ceiling, or drifts outside of the distance limit, your flight will be disqualified. The simulated altitude should generally not exceed 90% of the actual altitude limit.
- The rocket must be returned by parachute. It is acceptable to return the rocket in multiple pieces, as long as each piece has its own parachute. The maximum descent rate at landing should be 20 ft/s or slower.
- The rocket body tube must be at least four times longer than the body tube diameter. This requirement is not quite as odd as it might seem at first. The calculations used by most rocket simulators are not valid for very fat rockets.

You might add your own requirements to this list. For example, the Level 3 flight can be expensive, although there are many ways to cut costs. What is your budget? Your flying site might be relatively small, and winds might be relatively high, especially at altitude. You might add dual deployment to the list of requirements to help keep the rocket inside the waiver area.

No matter what, though, start your project by creating a well-thought-out set of requirements.

Your Certification Team

The composition of the certification team varies slightly depending on whether you are being certified by NAR or TRA. Either way, your primary mentor will be a senior member who is approved by the national organization. In both cases, a second person must sign off on the paperwork.

For NAR, this first member of your certification team must be a member of the NAR Level 3 Certification Committee, or L3CC. You can find a list of current members at the NAR website. This person will be involved throughout the design and construction process, so picking someone who is geographically close is important. The second certification team member can be any NAR member with a Level 2 or 3 certification. This person does not need to be involved right away, although it doesn't hurt if they are.

TRA flights must be approved by a member of the Technical Advisory Panel, almost always abbreviated as TAP. A second TAP member must sign some of the paperwork. I worked with two TAP members from the very beginning of my own certification flight, which turned out to be very useful, since I decided to fly my rocket at BALLS rather than our local flying site. The TAP member who approved my Level 1 and 2 flights did not go to BALLS that year, so my flight was approved by the second TAP member. You can find a list of TAP members at the TRA web site.

Whichever organization you select, get in touch with the selected L3CC or TAP member right away. Let the person know you are starting to plan a Level 3 certification flight. Show them your engineering requirements to see if they have any corrections or additions. You probably have a general idea what sort of rocket you want to build. Perhaps you would like to build a 4-inch fiberglass rocket, like Ganymede, coming up in Chapter 13. Your mentor might steer you away from that rocket because local flight restrictions make it very hard to keep under the altitude waiver, or might have a prepared outline for the engineering package. In any case, it is a good idea to discuss your plans with the L3CC or TAP member even before you start the engineering package.

The Engineering Package

The major document for your Level 3 certification is an engineering plan describing your rocket, how it was built, and how it is expected to fly. This section provides an outline and discussion of what should go in that document. It follows the excellent outline NAR provides on its website, but also fulfills the requirements for TRA. NAR also has a sample engineering package on its website.

Before getting into the details, though, let’s step back and set some expectations. Your L3CC or TAP mentor may have some specific requirements or recommendations, but in general, keep in mind that there is no requirement to write a production-quality document for your engineering package. It can be a relatively short, concise document consisting of hand-drawn plans, or it can be a polished digital document with embedded photographs or videos. This is your project. You need to meet the minimum requirements outlined here, but beyond that, the only people you have to satisfy are your mentor and yourself. If the content and format of the document work for the two of you, it is acceptable.

Also, this document should be written in two stages. The first is a planning stage. Write all of the document you can without actually buying any parts for the rocket. Create the plans, write your checklists, pick a motor, and run the simulations. This planning step will help you think through all aspects of the design before you shell out money for parts that you might end up exchanging for an alternative. At this point you have a great plan for your Level 3 attempt, and it’s time for a review by your mentors. Their suggestions may save you a great deal of time and money, as their experience with rocketry and local flying conditions will allow them to make suggested changes well before you start buying parts. Once that review is complete, buy your parts and build your rocket. With the rocket complete, go back and fill in the portions of the document that remain.

Introduction

The first section starts with a general overview of the rocket and flight. This is a good place to list or describe your project requirements. Give a brief description of the rocket, motor, and flight. Be sure to mention any novel design features, risks associated with those features, and how the risks are mitigated.

This section could be fairly short and still meet all of these requirements. For example, here's an introduction using Ganymede (discussed in Chapter 13) as an example:

Ganymede is a 4-inch-diameter, 90-inch-long, all-fiberglass rocket. It will fly on an AeroTech M1279M motor. Using RockSim, the simulated altitude is 13,831 feet, close to but still well under our local altitude limit of 15,000 feet.

The rocket uses dual deploy to bring it down close to the launch pad, keeping it inside the waiver area. A single 36" hexagonal parachute is deployed at apogee, and a 60" Sky Angle parachute is deployed at an altitude of 1,000 feet.

The projected altitude is a bit over 90% of the waiver altitude. As will be seen, previous simulations show that the actual altitude is generally a bit below the simulated altitude, so the risk of flying too high is minimal.

SCALE DRAWING

Throughout this book, you've been using RockSim or OpenRocket to design and simulate rockets. You will need to do the same for this rocket. The drawing produced by either of these programs is perfectly adequate for this section. It shows the major dimensions, center of pressure, caliber, and center of gravity.

NAR also asks for the aft limit for the center of gravity. This is the position one caliber in front of the center of pressure. It's handy to know, since you can balance the final rocket to find the approximate center of gravity. Knowing the aft limit gives a quick final check on the stability of the rocket.

Construction

This section describes the materials and techniques used to build the rocket. Look at the construction chapters in this book. Each has a table showing the materials used, photographs showing the steps and techniques used for construction, and a description of the process. That's what you need here, although not necessarily to that level of detail. Remember, you need to get the point across. You don't have to write perfect, publication-quality prose.

You must provide a complete list of all parts that will be used. This includes major parts, like the body tube. Will it be fiberglass? If not, and if the rocket will exceed Mach 1, expect your mentor to take a very close look at the possibility your rocket will collapse from aerodynamic forces. What sort of launch lugs are you using? Are they sufficient for the weight of the rocket? Your list should even include types of glue, fasteners, fillets, and other reinforcements. Be very complete in this section. If it will fly with the rocket, list it.

Cover construction techniques. Be sure to include drawings that show where the fillets will be, what type of glue will be used where, and how the glue will be cured. Epoxy dries better at warmer temperatures. If you are building your rocket in a colder climate in the winter, will you bring the rocket indoors for the glue to cure properly? Will your fillets be large, and if so, will you be using any sort of filler? If you decide to fiberglass any components, how many layers will be used, and in what direction will the grain of the fabric lie? Are you using screws or bolts? Will you use Loctite to make sure they don’t rattle loose? These are all important questions for any rocket, but especially one this size. Be sure the answers are in your construction section.

Your introduction contained a scale drawing of the rocket. This section needs to expand on any details the overall drawing does not show. In particular, you need to show where the motor mount centering rings are placed, how fins are attached, where the launch lugs are located, and how the instrument bay is constructed.

Be sure to discuss anything that is even remotely unusual. For example, breakaway launch lugs are popular on some rockets. If you plan to use them, that’s certainly something you should discuss. Some people use weight to reduce altitude. A popular method is to use water or sand that gets dumped at apogee. If you intend to drop water, sand, or anything else from the rocket in flight, discuss the reasons and mechanism in detail.

NAR recommends a completely separate section for the recovery system, so you can skip details about how the recovery system works and how the components are attached for now.

The initial package you show your mentors consists of drawings and descriptions, but the final package should also include photographs. In particular, it should have photographs showing the internals. For example, you should include a photograph of the motor mount with the centering rings attached before it is mounted in the rocket, as well as ones that show how the fins are attached, including the interior fillets. Include a ruler or a quarter (which is very close to 1 inch in diameter) as a scale reference in photographs where the size may not be obvious. You can also use the same technique you see in this book, where most photographs are taken with a cutting board for a background. The major divisions on the cutting board are also 1 inch apart.

It is also a great idea to invite your certification team over to inspect the rocket at key points of construction. An M motor is a powerful device. They'll want to make sure the rocket will stand up to that power.

Recovery

According to NAR statistics, a staggering 72% of model rocket flight failures are recovery system failures. This includes flights where pieces fell off, the parachute did not open, and the rocket returned ballistically. Many of the flights monitored by NAR are low-power rockets, where the danger is relatively small, but a Level 3 rocket is very different from a few ounces of light paper tube, balsa wood, and plastic. That's why the recovery system gets its own section. You don't want a failure with a large Level 3 rocket.

Start by describing, in general terms, how your recovery system will work. For virtually every Level 3 rocket, this will mean flight computers controlling dual deployment, with a small parachute or streamer deployed at apogee and a larger parachute deployed about 800–1,000 feet from the ground. Be prepared to defend your choices if this is not what you are planning.

The detailed description consists of six parts: recovery speed, venting and shear pins, flight computers, the recovery chain, recovery charges, and testing. Many of these sections need some sort of calculation. In all cases, tables or manufacturer's recommendations can be used instead of an actual calculation, but be sure to include the source for the table or recommendation.

RECOVERY SPEED

Chapter 9 described parachute selection in detail. Use that chapter to decide on the type and size of parachutes you will use at altitude and for the final descent. NAR recommends a maximum descent rate of 20 ft/s for landing. This might seem a bit slow, but this is a large, heavy rocket. As you recall, the landing energy is proportional to the weight of the rocket times the square of the speed. Reducing the speed of the rocket dramatically reduces the energy it will impart when it lands.

Show the complete calculation for recovery speed, including the coefficient of drag for the parachutes, the weight of the rocket, and the calculated terminal velocity. If the parachute uses parachute bags, cable cutters, or any other unusual mechanism, describe it fully.

NOTE

Be sure to recheck the recovery speed calculation once the rocket is built and you have an actual weight.

VENTING AND SHEAR PINS

Your flight computer needs vent holes to work properly, and the parachute bays need vent holes so a rapid ascent does not overpressurize the compartment, forcing the rocket apart early. Refer to “Finding Altimeter Vent Hole Sizes” for help calculating vent hole sizes. Be sure to include the calculations here.

Level 3 rockets that fly high and fast almost always use shear pins to prevent drag separation of the rocket and to reduce the chance that the rocket will separate because of rising pressure in the parachute compartment. Include the size and location of the shear pins, or the reason you don’t think you need them.

FLIGHT COMPUTERS

Describe where the computers will be mounted, how they will be powered, and how they will be turned on and off. Notice I said computers, not computer. Some sort of backup deployment system is required by NAR. While that can be an ejection charge on a motor, most M motors don’t use ejection charges. Plan for two computers from the start.

Include the make and model of the flight computers, along with a brief description of their sensors. Most flight computers use barometric sensors, but most also use accelerometers for launch detection. Many Level 3 rockets will break the sound barrier. For these, it is important to use a flight computer that uses some sort of algorithm and sensor combination to guard against spurious altitude readings as the rocket passes through the sound barrier. If your rocket will break the sound barrier, be sure to get computers that can handle it, and say so in this section.

Each computer must have its own power chain. That includes separate batteries and arming switches. It also includes separate igniters for both the apogee and dual-deploy ejection charges. While there is no requirement to use separate ejection charges, it is still the most common choice. Why skimp on a little black powder? A completely redundant ejection charge could easily be the difference between a safe recovery or a lawn dart.

You must be able to arm and disarm the computers on the launch pad. This does not have to be super fancy, like the mechanism shown in “Modifying Deimos or Phobos for Dual Deploy”. It can be as simple as twisting two wires together, as long as you have some sort of access panel that allows them to be untwisted while the rocket is on the pad. You also need some way to disarm the computers after the rocket lands. This covers disarming unfired ejection charges so the rocket can be safely handled.

Include a circuit diagram showing how the computers, batteries, arming switches, and igniters for ejection charges will be wired. Don’t include the complete circuit diagram for the computers; it’s fine to show them as a block with their various input and output connections. Circuit design software like Eagle, used in this book, is great for creating your circuit diagram, but a neat hand drawing will do just fine.

RECOVERY CHAIN

Methodically work through the entire recovery chain, starting with the eye bolt that connects the recovery system to the rocket and working your way to the parachute. Include how the eye bolt is mounted in the rocket; the kind and rated strength for the bolt; the length, rated strength, and attachment method for the shock cord; the rated strength for the quick links or any other attachment mechanisms; and the method for connecting the parachute to the shroud lines.

The parachute must be protected from the hot gases of the recovery charge. While some kind of recovery blanket is common, there are other mechanisms. Describe the mechanism you’re using and how it is attached to the rocket.

RECOVERY CHARGES

Show your calculations or cite sources for the choice of recovery charge size. This is covered in detail in “Predicting the Recovery Charge Size”. Describe how the ejection charges will be contained until deployment. Be sure and describe the type of igniters used to fire the ejection charge and how they will be secured.

TESTING

Calculations and theory are fine, but an actual test is the only way to verify your choices, especially the choice of ejection charge size. Do a complete test like the one described in “Testing Recovery Charges”. Include photos and videos if possible. This is also a great time to invite your mentor over to watch, both to show that your recovery system will work and to get comments and advice on improvements.

I’ve seen several people bring their rocket to a launch specifically to do a recovery system test. These tests are treated just like a launch, running through a full checklist and performing a countdown, but the rocket never leaves the launch pad. This is a great way to make sure you mentor or others in the club get a chance to help with suggestions or to correct any issues.

Stability Evaluation

While we tend to concentrate on the center of gravity and center of pressure, if you think back to the material you have already read, there is a lot more to stability than just the rocket's caliber. Stability literally starts on the launch pad, and that's where this section should begin.

Describe the launch buttons or whatever mechanism you will use to guide the rocket for the first few feet of flight. Be sure to include information about how the launch buttons are attached. Describe the launch pad, and in particular the length of the launch rod. Level 3 rockets tend to be fairly large. Unlike smaller rockets, the weight of the launch pad may not be sufficient to keep the launch pad itself on the ground. Describe any stakes or tie-downs used to secure the launch pad.

Your rocket must be going fast enough for the fins to work before it leaves the launch pad. The generally accepted minimum launch speed is 45 ft/sec, but that really is a minimum. It is easy enough to get twice that with most Level 3 rockets. Include a calculation or the number calculated by your simulation showing how fast the rocket will be traveling as it clears the launch rail. If it is a bit on the slow side, consider adopting more stringent requirements for wind speed than the generally accepted 20 mph maximum.

You also need the traditional center of pressure and center of gravity calculations. Your simulation gives the location of the center of pressure. The center of gravity needs to be at least one body tube width in front of the center of pressure. Mark the calculated center of pressure and the actual, measured center of gravity. A Sharpie works great for this.

NOTE

Don't mark the calculated center of gravity on the rocket. Wait until the rocket is complete and mark the actual center of gravity. Depending on the particular motor you use, you may need to wait until launch day for a final check, but you can get a pretty good idea with a partially assembled motor.

Flight Profile

Describe the flight itself. This is essentially a summary of the flight simulation. A printout of the simulation is probably acceptable, although you can summarize the key points, too.

You may want to include more than one simulation. Your club may have multiple launch locations. The rocket’s performance can vary quite a lot depending on the altitude of the launch site. You might want to include simulations for high and low temperatures, which can also have a big affect on the flight parameters. Flight simulators can simulate the effect of wind; be sure to check the simulated recovery distance against the expected flight waiver.

This section should include the specific motor to be used for the certification flight. It must be an M, N, or O motor that is currently certified by NAR or TRA. Check their websites for a list of certified motors.

Be sure and include the speed as the rocket leaves the pad, the maximum speed, and the landing speed. Include the maximum acceleration, which gives some idea of the forces on the internals of the rocket, and the coefficient of drag, which gives some idea of the forces on the external components.

List the expected altitude. This should generally be at least 10% lower than the FAA waiver on flight day.

Give the launch weight and recovery weight for the rocket.

Checklists

You’ve seen checklists throughout this book. They are a required part of your engineering package, and you will be expected to use them for the flight.

You can use the checklists in this book as a guide. NAR also includes a very detailed outline of its checklists. Honestly, this is one area where I think they go overboard. According to Atul Gawande’s *The Checklist Manifesto: How to Get Things Right*, an ideal checklist should have five to nine items. If it gets much longer, it becomes tedious to use and is often ignored. It should be short, specific, and to the point. It should not include instructions on how to do routine tasks like pack a parachute and wrap it in the recovery blanket, but it should include something like "pack the parachute in the recovery blanket."

With that in mind, be sure you have checklists for both normal and abnormal situations. Here's a good checklist of checklists. It includes the checklists from NAR's outline, plus an additional one of my own.

1. Things to take to the launch
2. Prelaunch checklist
3. Launch checklist
4. Post-flight checklist
5. All recovery charges did not fire
6. Misfire checklist

If you find a checklist is growing too long, break it up into several smaller checklists. For example, instead of a prelaunch checklist, you might write a rocket assembly checklist and a launch pad checklist.

Keep these on a clipboard or in a notebook on launch day.

If your mentor wants more detail than you are inclined to put in the checklist, it's likely because they want to know you have thought through all of the contingencies. In that case, one good strategy is to put your checklists in the engineering package with comments under each checklist item. This shows that you have thought through the details—and forces you to do so!—while keeping the checklists themselves short and to the point. On launch day, use the checklists without the comments.

Building Your Rocket

Once your L3CC or TAP mentor approves your engineering package, and *only* once they approve it, buy the parts and start building your rocket. For must of us, this is the fun part. Take your time and enjoy it.

Remember to take photographs for the final version of your engineering package. Plan plenty of extra time for ejection charge tests and coordinating visits with your mentor.

Flight Day

Your L3CC or TAP member will probably want to watch you build your motor and assemble the recovery system. I like doing most of this work the night before the launch. If you do, too, invite your mentor over for the final preparations.

Each organization has paperwork that needs to be filled out and signed. Go to the NAR or TRA website and download the latest paperwork. Fill out everything you can, and then take the paperwork with you to the launch on a clipboard with a pen. Make things as easy on your TAP or L3CC member as you can. It is up to you to make sure the paperwork gets filled out and turned in.

By now, you are quite ready for the flight, and you are probably anxious to get your rocket in the air! In addition to all of the other preparation, following all of the checklists, and coordinating with your evaluation team, there is one final step to take: you need to check the weather.

This is more than a check of the ground weather conditions. That’s important, but you also need to check conditions aloft. Level 3 rockets are either very large or they will go very high. A typical Level 3 rocket like Ganymede, which we’ll build in the next chapter, can easily hit 13,500 feet. If your launch site is at a high altitude, that’s enough to reach the jet stream. Even if you don’t hit the jet stream, winds aloft are often very different from surface winds. Unless you want to risk drifting outside of the waiver area, you need to check the winds aloft for any high-altitude flight.

Fortunately, pilots have great resources for keeping track of the winds aloft, since that’s where they work. You can get the same weather reports pilots use. One source is the Aviation Weather Center. Spend some time getting used to this site well before launch day, and then check the site on launch day to make sure your rocket will not drift too far.

Once everything is ready, take one more moment. It took a lot of preparation to get to this day. Were you rushed? Did you follow your checklists? Does everything feel right? I have literally walked out to the pad and taken a rocket off when there was nothing left to do but push the launch button because things just did not feel right. Perhaps the winds picked up, or some clouds were getting a bit close. It is far better to pull a rocket off of the pad because you are not sure it is ready than it is to fling 30 pounds of aluminum-tipped fiberglass into the air at Mach 1.5 and find out later the parachute popped off because a quick link wasn't closed.

OK, so you're ready? Point that tracking antenna at the rocket, give the LCO the final OK to launch, and enjoy the moment.

Chapter 13. A Level 3 Rocket

There are many ways to build a Level 3 rocket. Some people like to build rockets that get the most out of every newton, reaching for high altitude or fast speeds. Others like to build very large rockets. The rocket we'll look at in this chapter (Figure 13-1) is a bit of a compromise. It's a fairly standard design, but it's packed into a roomy 4"-diameter fiberglass airframe so you have plenty of room to work. It will stay below 15,000 feet on an AeroTech M1297W, but it will also do about Mach 1.5.

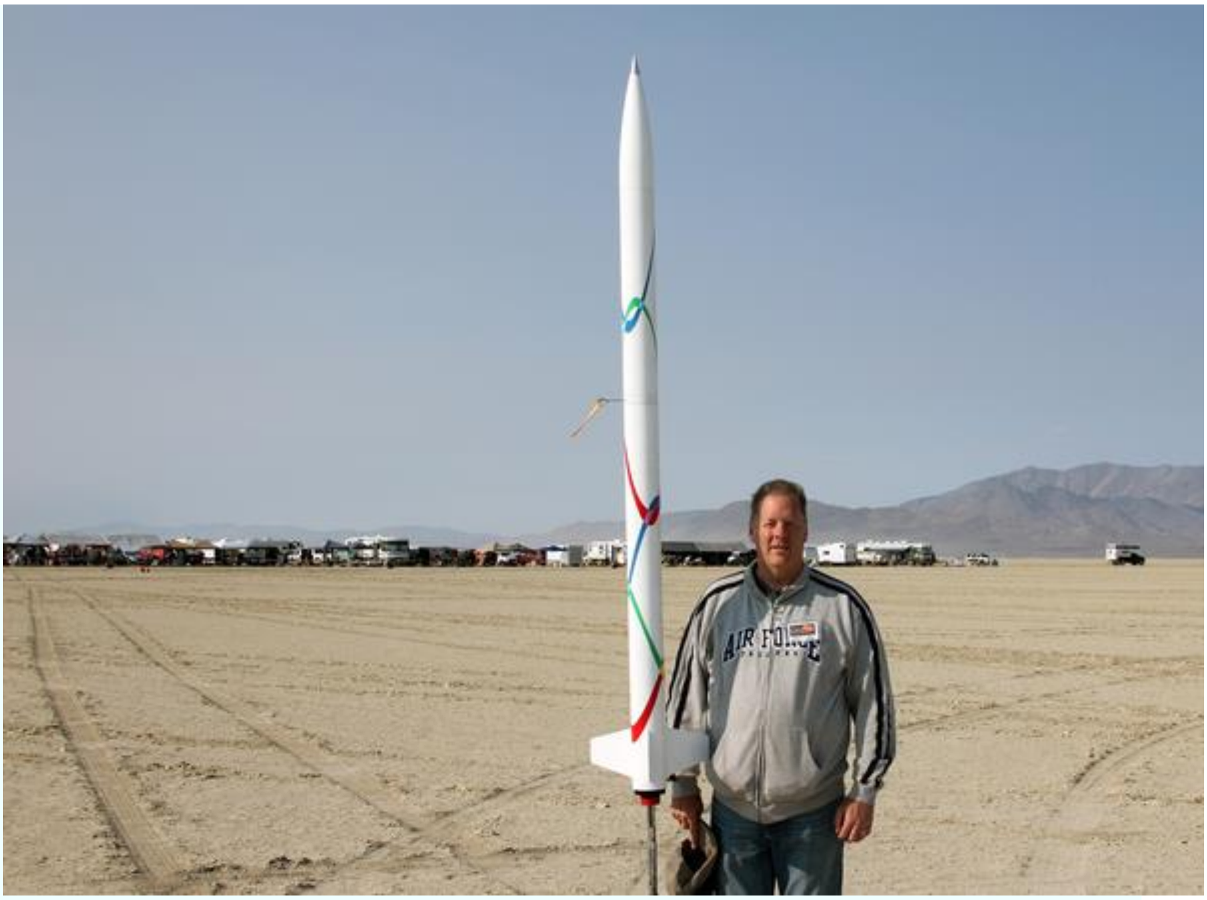


Figure 13-1. The author prepares Ganymede for a flight at BALLS 23.

Ganymede

Ganymede

Ganymede is the largest moon in our solar system, larger than Mercury and almost as large as Mars. The icy surface probably covers a salty ocean that has the potential for life.

Ganymede is one of the four Jovian moons Galileo Galilei discovered when he turned his telescope on Jupiter. On the first night, he believed he had found a chance alignment of stars near Jupiter, but after looking again the second night, he realized the objects were moving with Jupiter. His conclusion that there were moons orbiting Jupiter helped convince scientists of his day that the planets, including Earth, rotated around the Sun, instead of all of them rotating around the Earth.

Ganymede is an all-fiberglass rocket with a classic high-power rocket design. In many ways, it is very similar to the dual-deploy version of Phobos, a fact that will make this chapter considerably shorter than most of the construction chapters in the book. This chapter assumes you are familiar with all of the information from earlier in the book, especially the construction details for Phobos, the safety tips regarding working with fiberglass, and rockets that use dual deployment with a drogue and main parachute.

There are several companies that supply fiberglass parts for rockets. Ganymede uses parts from Madcow Rocketry. The parts list is shown in Table 13-1. As you know by now, you can make many substitutions to this basic parts list. Depending on what other motors you might want to use in the future, you might choose to make the booster a bit longer. Madcow Rocketry also sells colored versions of its fiberglass tubes. Other than color, they are the same tubes used here. If you don’t like paint for some reason, the colored tubes could save you from a boring rocket.

Part	**Description**
Nose cone	The nose cone for the rocket. Madcow sells several kinds, and all will work.
Booster airframe, 4” diameter, 45”	Sold in either 30” or 60” lengths.

Part	Description
long	
Payload airframe, 4”, 24” long	Sold in either 30” or 60” lengths.
Switch band, 4”, 1” long	Cut this from the airframe or booster tube.
Tube coupler, 12” long	Fiberglass tube coupler for 4” airframe tubes. This is sold in several lengths. Get the 12”-long part.
Coupler bulk plates (2)	These form the inside bases for the altimeter bay lids. See the text for alternatives.
Airframe bulk plate (2)	These form the outside base for the altimeter bay lids. See the text for alternatives.
Fins (3)	Cut your own from G10 fiberglass stock, or order precut fins from PML. Precut fins are shown in the text.
Centering rings (2)	These fiberglass centering rings form a solid motor mount wher used with a 75 mm fiberglass motor tube.
3” motor tube, 30”	This is the airframe for a 75 mm motor, just as the 4” airframe for this rocket is the airframe for a 98 mm motor.
Motor retainer	Madcow sells several retainers, including tail cones. The text shows a standard retainer. Be sure to get the retainer for fiberglass motor tubes if you are following the plans in this chapter. If you substitute another motor tube, change the retainer to match the type of motor tube.
Rail buttons (2)	This is the Madcow part number for the same rail buttons used on previous rockets in the book.
Nuts for rail buttons (2)	You can buy these or make them from 1/8” x 3/4” aluminum stock, as we did for Callisto, Deimos, and Phobos.

Part	Description
Eye bolts (3)	Two of the eye bolts are attached to the bulk plates on the altimeter bay. They are used to attach the shock cord that holds the booster to the payload bay. The third is used as an attachment point on the nose cone; if you select a different nose cone, you may need to use a different attachment method. The Madcow eye bolt has a 1/4-20 thread.
Washer	A washer is used to spread the force across the fiberglass bulk plate. Use at least a 3/16" washer.
Quick links (6)	Madcow sells 1/4" quick links that work well for this rocket. Everbilt, available in many hardware stores, has one rated at 880 pounds.
Tubular nylon	Shown is the same 9/16" tubular nylon from previous rockets. Madcow sells several kinds of shock cord material that will work, such as its 1/2" flat nylon, available in several colors. Ge 60 feet.
Nomex tubing	Use some form of shock cord protector, as seen on earlier rockets.
1/4-20 threaded rod	Two 13"-long pieces will form the backbone of the altimeter bay. Available from most hardware stores.
1/4-20 hex nuts (6)	Used to secure the altimeter bay. Available from local hardwar stores.
1/4-20 wing nuts (2)	Used to secure the altimeter bay. Available from local hardwar stores.
Hillman 1/4" x 3/8" x 1" stainless steel spacers (4)	These are used to attach the avionics bay sled to the 1/4-20 threaded rod. Pretty much any sturdy tube that slides over the rod will do.
Electronics	You will need two flight computers, along with the switches, batteries, wire, terminal blocks, and wood needed to hold them, plus some kind of tracking radio. This will probably be the

Part	Description
	same as those used for earlier projects.
Drogue parachute	Use a small drogue parachute, such as a 24” nylon parachute from an earlier rocket.
Main parachute	As designed, this rocket is best flown with a parachute in the 50”–60” range, depending on the size of motor and the type of parachute used. See Chapter 9 for ways to find the proper size.
#4 1/2”-long pan head screws (3)	Used to attach the parachute bay airframe to the instrument bay.

Table 13-1. Parts list for Ganymede

Building Ganymede

Cutting and Collecting the Fiberglass Parts

Many of the fiberglass parts can be purchased precut, but even with precut parts, there will still be a few places where you need to drill, cut, or sand the fiberglass. Be sure to read “Cutting Fiberglass” before cutting any fiberglass.

Ganymede uses three G10 fiberglass fins cut from 0.093”-thick stock. You can cut your own from stock sold by Madcow Rocketry or buy them precut from Public Missiles Ltd. If you decide to cut your own, use 3/32”-thick (0.09375”) sheets—although going up to 1/8”-thick sheets would not be overkill on this rocket. If you order precut fins from PML, get FIN-C-02, which is a 0.09375” fin with the dimensions shown in Figure 13-2.

Madcow Rocketry sells body tubes in several precut lengths. They will cut the tubes for you, or you can buy the longer tubes and cut them yourself. The airframe is made from 4”-diameter G12 fiberglass. The booster body tube is 45” long, the upper parachute bay is 24” long, and the avionics bay uses a 1”-long section of tubing. These lengths are not especially critical. They primarily reflect the lengths of tubes available when I built Ganymede. The booster section is actually a little cramped at 45” long; extending it to 50” or even a bit longer would not be a bad thing.

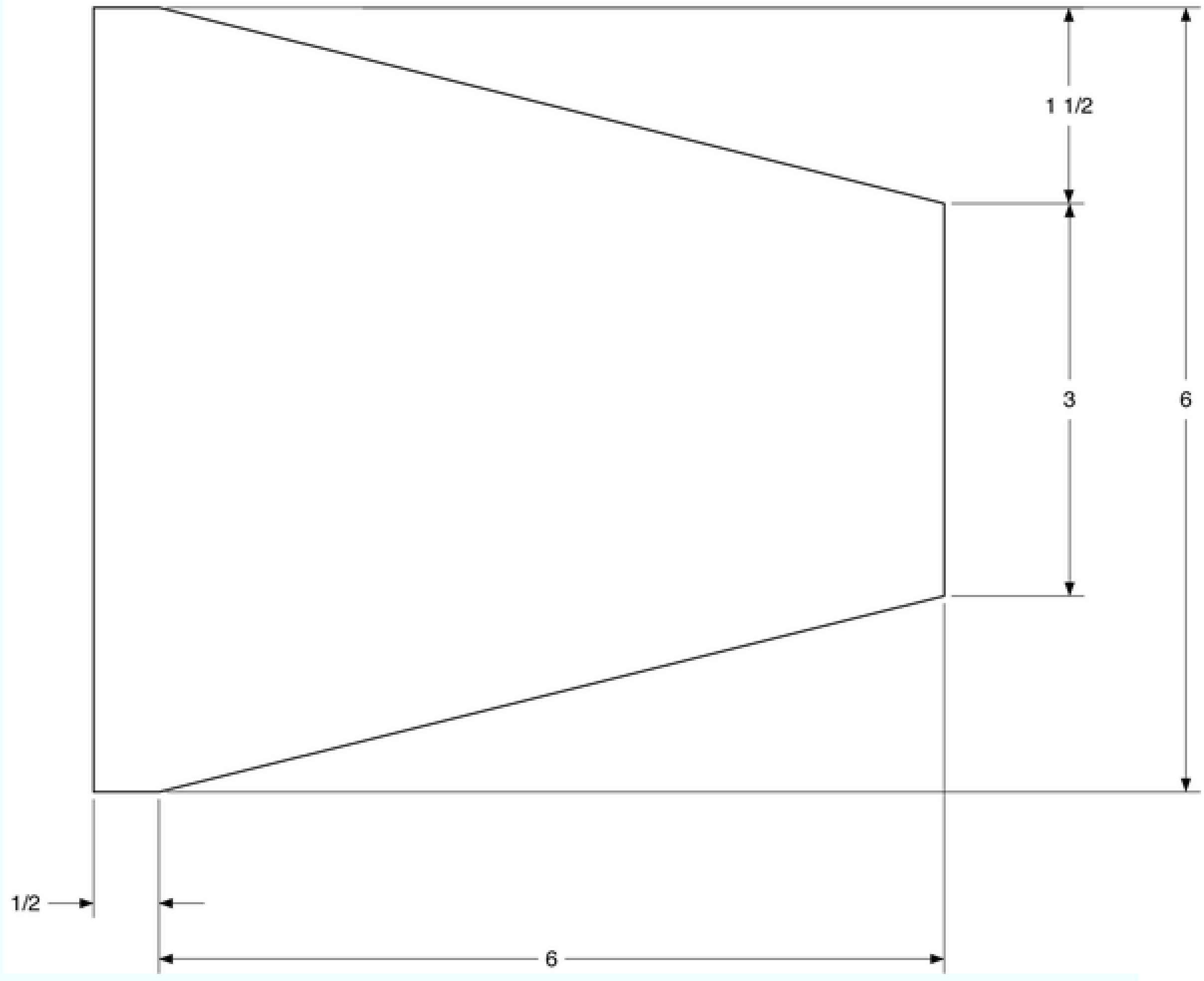


Figure 13-2. Cut three fins from 3/32” G10 fiberglass or buy them precut from PML.

Madcow Rocketry sells the remaining fiberglass pieces in the lengths needed, so they will not need to be cut. The motor mount is a 30”-long section of 3” G12 airframe, available in that length. It is not necessary to cut it, and I did not, but trimming it back to 24” will still accommodate a small M motor. Letting a longer motor poke past the end of the motor mount does no harm, either.

The avionics bay is a 12”-long piece of coupler tubing for the 4” airframe tube.

You will need two centering rings to hold the 3” motor mount in the 4” airframe tube. Madcow Rocketry labels these as 4” x 75 mm G10

CR. There’s nothing like keeping your units consistent, right? The reason, of course, is that we generally refer to the airframe size in inches, but the motor sizes are labeled in millimeters. This centering ring will hold the 3” airframe tube used as a motor mount.

As with Phobos, each of the two lids for the avionics bay is made from two bulk plates, one sized to fit into the tube coupler and one sized to fit into the airframe tube. You can buy the bulk plates separately and glue them together, as we did for earlier rockets, but Madcow Rocketry has another option. For the same price, you can buy the 4” / 98 mm G10 AvBay Lid, where the two pieces are already glued together. A second option is to buy the 4” Aluminum Bulkplate.

Finally, you will need a nose cone. The construction photos show the Madcow Rocketry 4:1 ogive metal-tipped fiberglass nose cone.

Assembling the Booster

Refer to “Building Phobos” for detailed instructions on properly aligning and building the booster section.

Cut three slots for the fins. The fins are positioned 1” from the base of the booster, and each slot is 6” long.

Drill the holes for the rail buttons and the vent holes for the parachute bay. If you bought the same rail buttons I did, they use 10-24 screws, so the holes for the screws should be 5/32”. Drill one hole 1” from the base of the rocket, centered between two of the fin slots, and the second hole at least 6” back from the top of the booster. The shorter distance at the base makes it easier to install the rail button once the motor mount is in place, while the 6” distance leaves room for the avionics bay to slide into the booster.

Drill three 1/8” vent holes around the top of the booster, about 5 3/4” from the end of the tube. See “Finding Altimeter Vent Hole Sizes” for information about calculating the vent hole sizes if you lengthen or shorten the booster tube.

Rough up the outside of the motor mount tube with coarse sandpaper to allow good glue joints. The forward centering ring will be mounted 1” from the end of the tube, so the area from about 3/4” to 1 1/4” from the end of the tube should be prepared for glue. Centering rings, fins, and motor retainers will be glued to the aft end, so rough up a full 7” section there.

Rough up the inside of the booster tube 29” into the tube and 3/4” into the tube, measuring from the base. Do the same to the area right around the fin slots on both the inside and outside of the airframe tube.

Glue one of the centering rings 1” from the end of the motor mount tube using 5-minute epoxy. Apply generous fillets to both the top and bottom of the centering ring where it meets the motor mount tube (Figure 13-3).

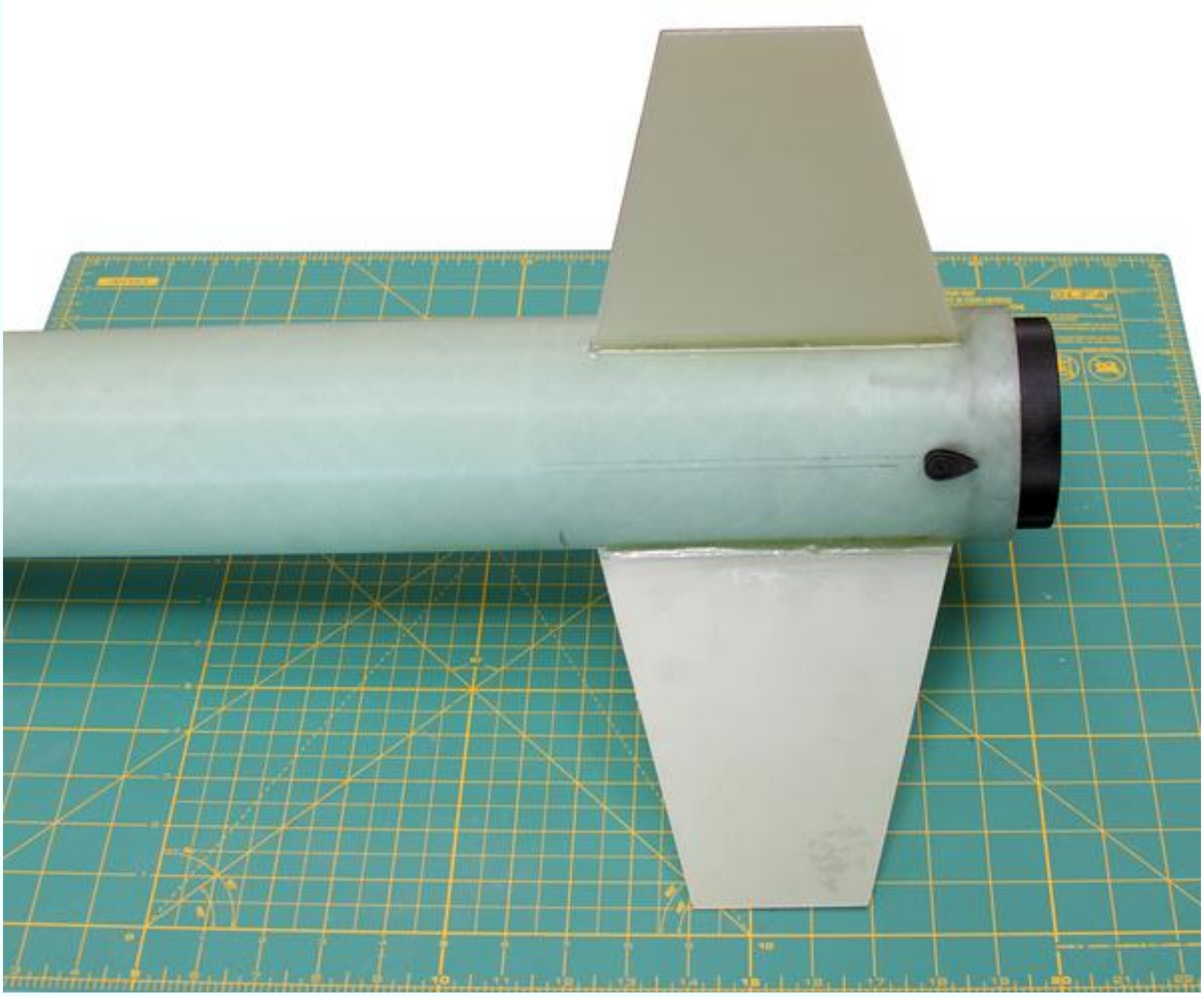


Figure 13-3. The tail section of the booster. The rocket is a bit long to show all at once!

After the glue thoroughly sets, apply a generous amount of 5-minute epoxy to the inside of the tube about 28” from the base, then slide the motor mount into place. Use the remaining centering ring to align the motor mount, wrapping dental floss around the centering ring so it can be extracted later. Stand the booster upright over wax paper while the glue sets.

Where’s the Shock Cord Mount?

There is no step in this section for mounting a shock cord in the booster. This is something you might consider, depending on the type of motors you intend to use with this rocket. Many 75 mm motors, including the one shown here, have a forward closure that is drilled for a 1/4-20 eye bolt. The directions in this chapter will make use of that, attaching the shock cord directly to the motor itself (see Figure 13-4). This is a very reliable mount, and also allows for easy replacement of worn shock cords.

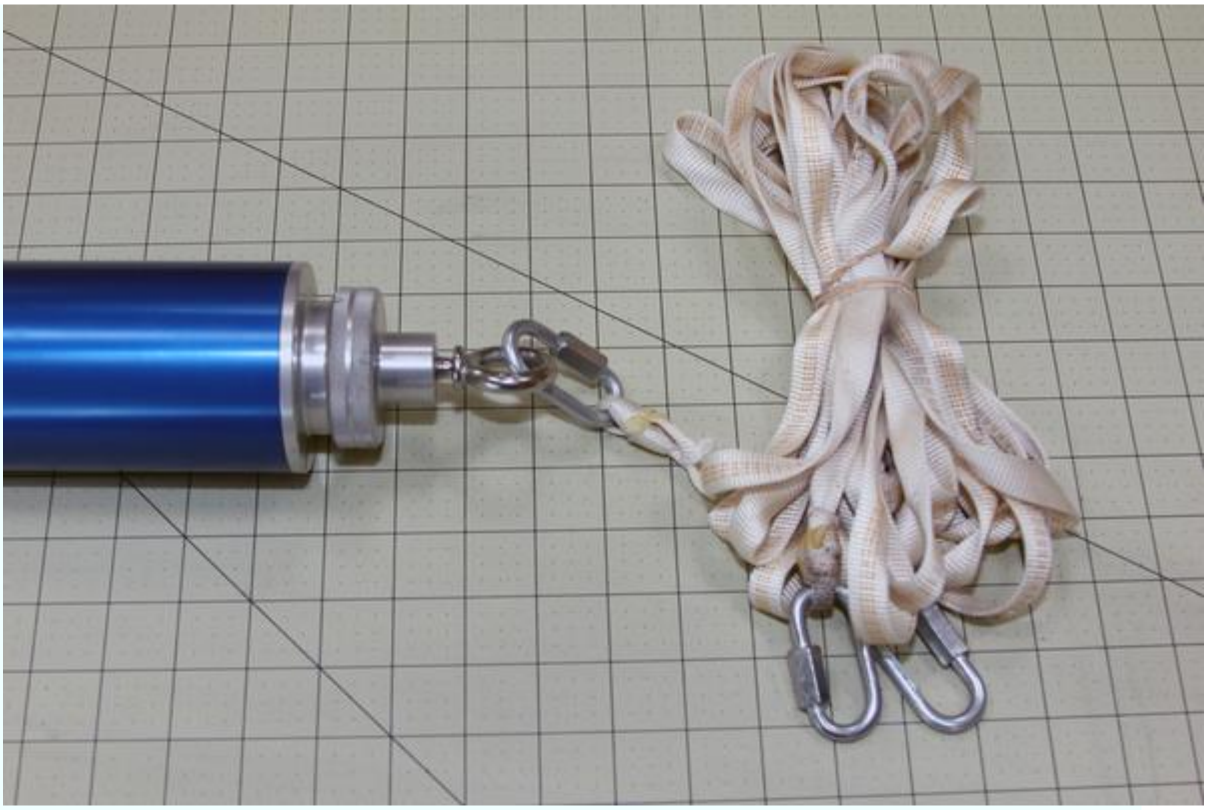


Figure 13-4. Many larger motors have a forward closure that allows a shock cord to be attached directly to the motor.

Turn the rocket over and remove the aft centering ring. Dribble slow-cure epoxy between the airframe and motor mount until the entire lower end of the forward centering ring is covered with epoxy. Use a flashlight to make sure you get epoxy everywhere. Don’t worry about glue that gets on the walls of the tubes unless it is on the portion of the motor mount where the fins will sit, or within 1” of the base of the rocket. Clean those areas with a paper towel soaked in rubbing alcohol before the glue sets, using a dowel or ruler to push the towel along the sides of the tube if the glue is too far to reach with your gloved fingers.

Tack the fins in place with fast-cure epoxy and allow them to set. Use a jig to align the fins, as you saw in “Cutting a fin template”. Once the fins set completely, apply very, very generous fillets between the motor mount tube and airframe, filling the area around the fins with at least 1/2” of epoxy, forming a square plug beside each fin. Apply normal fillets along the joints between the fins and the outside of the airframe. See “Installing the Fins” for details on forming proper fillets, although these will be considerably thicker, like those used for Phobos.

Glue nuts for the rail button screws to the inside of the airframe. Once the glue dries, install the rail buttons. See “Adding Launch Lugs and Rail Buttons” for thoughts on rail button nuts and attachment.

Glue the aft centering ring into place using fast-cure epoxy. Use a generous amount of glue on both the outside of the motor mount and the inside of the airframe. Once the centering ring is in place, stand the rocket upright over wax paper while the glue sets.

Glue the motor retainer into place using JB Weld or a similar high-temperature epoxy. Once the motor mount is in place, use regular epoxy to apply fillets to the aft side of the centering ring, standing the rocket upside down while the glue sets.

Avionics Bay Construction

See “Converting Deimos for Dual Deploy” for construction details for avionics bays, as well as a discussion of how and why they are used.

This is a much heavier rocket than Deimos, so the threaded rods used to hold the avionics bay together are thicker. While the specific strength varies with the type of steel used, a typical proof strength for the #10-24 threaded rod found in hardware stores is about 890 pounds, while the strength for 1/4-20 rods is more like 1,620 pounds. While the #10-24 rod would probably do, the 1/4-20 rod is a safer choice.

Cut two pieces of 1/4-20 threaded rod 12 5/8” long. These will serve as the rails in the avionics bay, which you see running the length of the bay in Figure 13-5.

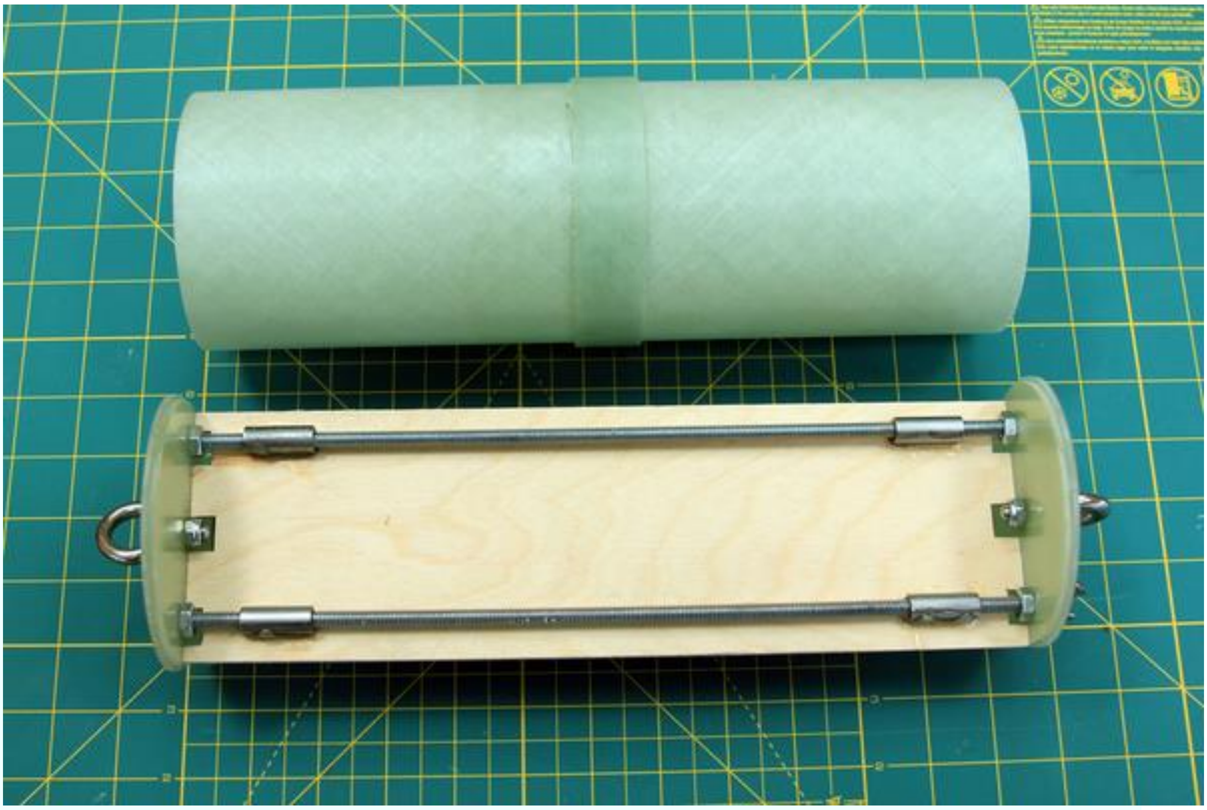


Figure 13-5. The avionics bay with the outer tube removed.

Cut a piece of 1/8”-thick aircraft plywood or some similar material for the avionics bay sled. The exact dimensions will vary a bit depending on your choice of sleeves that fit over the rails, the closures you select for the lids, and the nuts and bolts you select for the threaded rod. The one seen in Figure 13-5 is 11 13/16” long and 3 21/32” wide. Make sure the length of the sled allows the lids to close completely, with the sled just touching each lid.

There are several options for the avionics bay lids. The ones shown were made by gluing a Madcow 4” G10 Coupler Bulk plate, which just barely slips inside the coupler tube, to a 4” G10 Airframe Plate, which slips into the airframe tubes. Madcow also sells essentially the same thing premade, as well as an aluminum version. All work great. If needed, rough up the surface of the two bulk plates and glue them together with fast-cure epoxy, making sure the coupler bulk plate is exactly centered in the airframe bulk plate.

Each lid needs three holes, one for the eye bolt that serves as a shock cord attachment point and two for the 1/4-20 threaded rods that hold the avionics bay together while providing an attachment point for the sled. Madcow sells a 1/4” x 1” eye bolt that works well. It is a little long, so you have the choice of trimming it or cutting a slightly longer slot in the sled than the one shown in Figure 13-5. A quick web search tells us the proper hole size for a 1/4-20 rod is 17/64”. Drill one hole in the center of the lid, and two collinear holes 1 1/4” from the center.

Attach both eye bolts. Attach the threaded rods to one lid using two 1/4-20 nuts, one on either side of the lid. Slide two 1”-long spacers onto each of the rods. Add a nut to each rod, screwing it down just far enough so the lid will sit on the nut when the altimeter bay is fully assembled. See Figure 13-5 for the position of the nuts.

With the tube coupler removed, slide the lid onto the threaded rods and fasten it in place with two wing nuts. The nuts added in the last step and the wing nuts trap the lid in position. Glue the spacers to the sled using fast-cure epoxy. The assembly should like just like Figure 13-5 at this point.

Back when you were cutting airframe tubing, one piece was a 1”-long switch band. Glue this in the center of the tube coupler. Once the glue dries, drill three 1/8”-diameter holes evenly spaced around the switch band to serve as vent holes for the altimeters.

Upper Parachute Bay Construction

The upper parachute bay is pretty simple. The only point of interest is the shock cord attachment to the nose cone. While the specific nose cone you bought may differ, the one shown in this chapter has a metal tip. The tip is held in place with a 1/4-20 bolt and a small fiberglass disc. Remove that bolt and replace it with a 1/4-20 eye bolt, using that as an attachment point (see Figure 13-6).

Rough up the inside of the nose cone and the upper half of the tube coupler that comes with the nose cone. Glue the tube coupler in place.

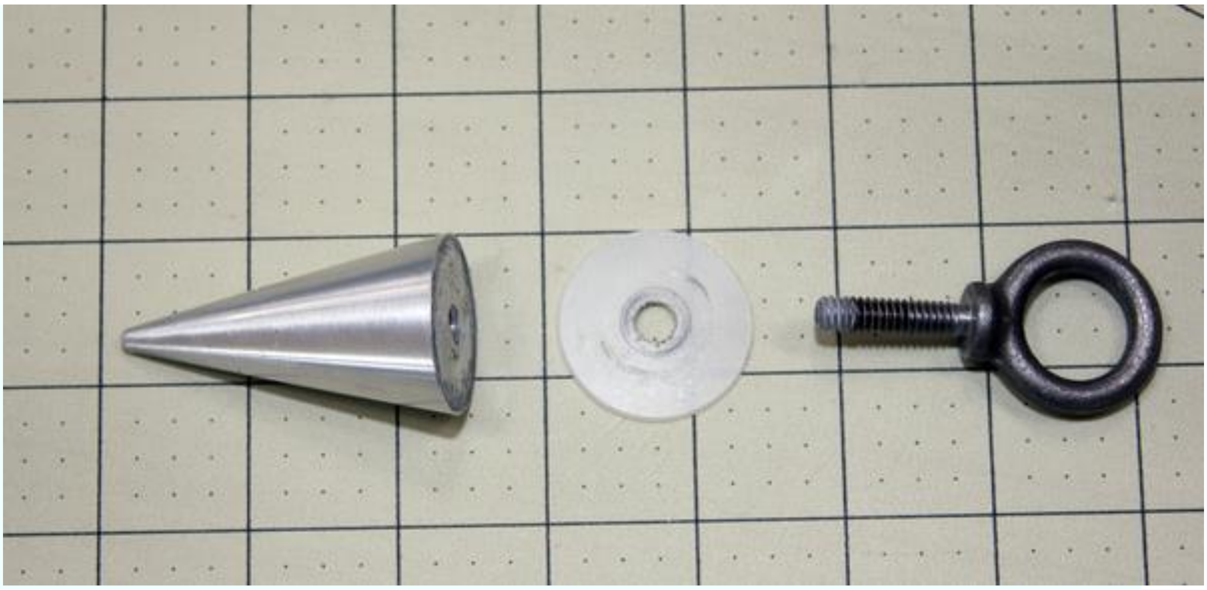


Figure 13-6. Replace the standard 1/4-20 bolt with a 1/4-20 eye bolt.

Drill three 1/8” vent holes evenly spaced around the forward end of the 24”-long upper parachute bay. These should be 3 1/2” from the forward end of the tube, unless you change the nose cone. In that case, make sure they are below the nose cone shoulder.

It really doesn’t matter whether you attach the parachute bay airframe tube to the nose cone or the instrument bay, but it needs to be attached to one or the other. Assuming you attach the airframe to the instrument bay, insert the avionics bay into the aft end of the airframe tube and drill three 3/32” holes evenly spaced around the airframe, drilling through into the instrument bay. Use three 1/2”-long #4 pan head screws to attach the airframe tube to the instrument bay.

Shear Pin Holes

We discussed shear pins back in “Shear Pins”. This rocket should definitely use them. Assuming you are using the 1/16” styrene pins from that section, insert the nose cone into the upper parachute bay and drill three 1/16” holes evenly spaced around the airframe tube. These should be positioned so they are about halfway down the shoulder of the nose cone, with the holes going through both the airframe and the nose cone shoulder.

Insert the instrument bay into the booster airframe and repeat the process, drilling three 1/16” holes through the booster airframe and the instrument bay.

Building the Shock Cords

See “Shock cord” for detailed information about shock cords.

Build two identical shock cords, one to connect the booster to the instrument bay and the other to connect the instrument bay to the nose cone (see Figure 13-7). These shock cords are going on a rocket that is roughly 7 feet long, so using the rule of making the shock cord three to five times the length of the rocket, each shock cord should be 21 to 35 feet long. I went for 30 feet each. This is a large, heavy, high-flying rocket, so 9/16” tubular nylon is appropriate.

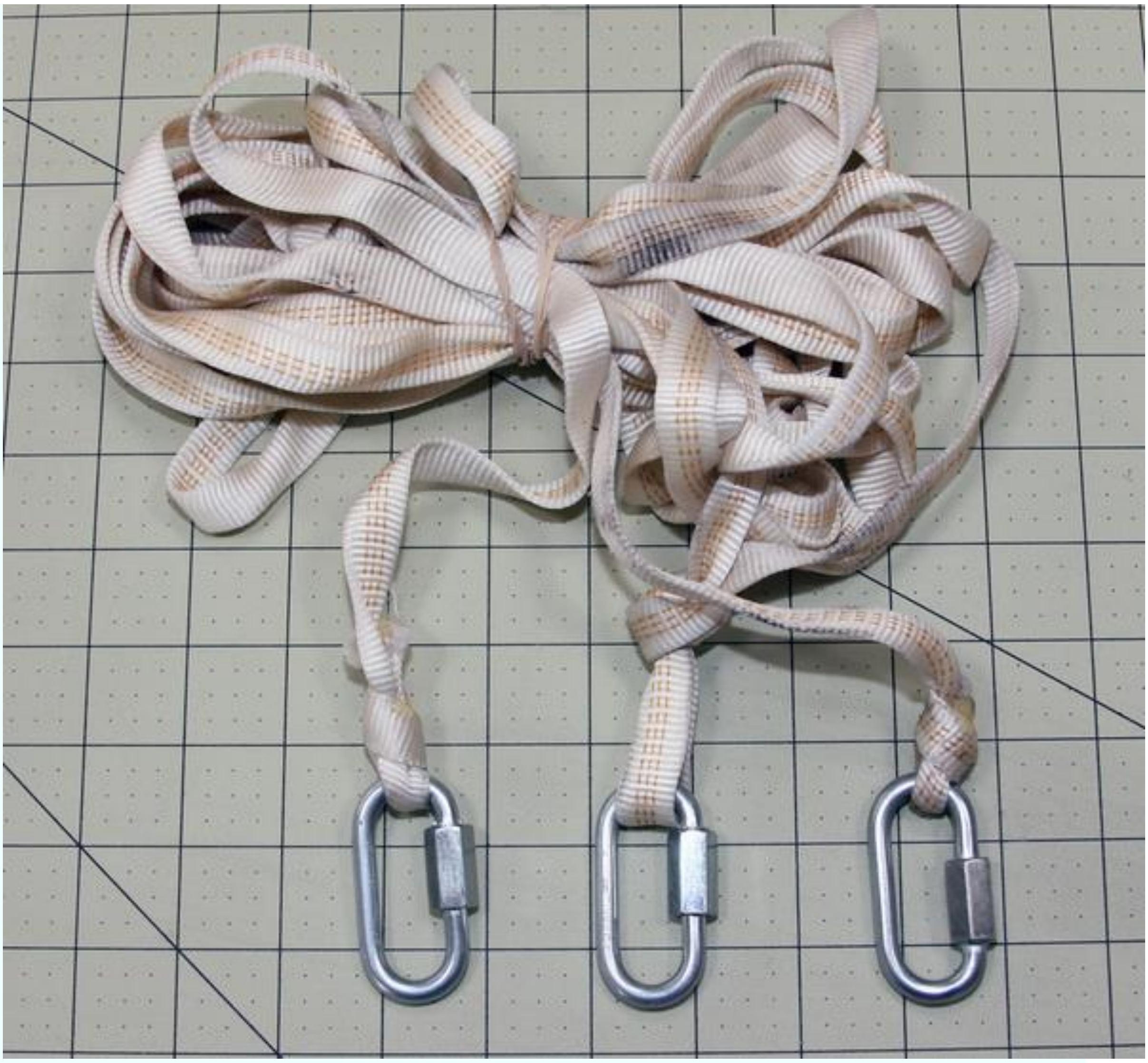


Figure 13-7. Build two 30-foot-long shock cords from 9/16″ tubular nylon.

Get six quick links, one for each end of each shock cord and one for the parachute attachment point. The tubular nylon has a rated strength of about 1,000 pounds, depending on the kind you buy. Be sure to get quick links in the same range. Everbilt, available in many hardware stores, has a 1/4” quick link rated at 880 pounds.

Use a buntline knot at each end of the shock cord, using a small amount of epoxy to keep the knot from unraveling. Tie an overhand knot 1/3 of the way from one end. Attach a quick link at each knot, as shown in Figure 13-7.

Installing Computers

Ganymede is a large, heavy dual-deploy rocket that depends on flight computers and hand-wired circuitry to deploy the recovery system that will return the rocket safely to earth. Like any rocket with that description, Ganymede should be flown with two completely redundant systems for deploying the parachutes. See Chapter 7 for detailed thoughts on creating a safe recovery system.

That said, the specifics of mounting and wiring the flight computers and recovery system will depend on the specific computers you select.

Figure 13-8 shows the instrument bay with a Raven and a StratoLogger flight computer. You can clearly see the redundant batteries, one for each computer. Two switches are mounted on the back, as described in “Modifying Deimos or Phobos for Dual Deploy”. The plastic box secured with a yellow zip tie holds a tracking radio, with the antenna extending up between the other components.

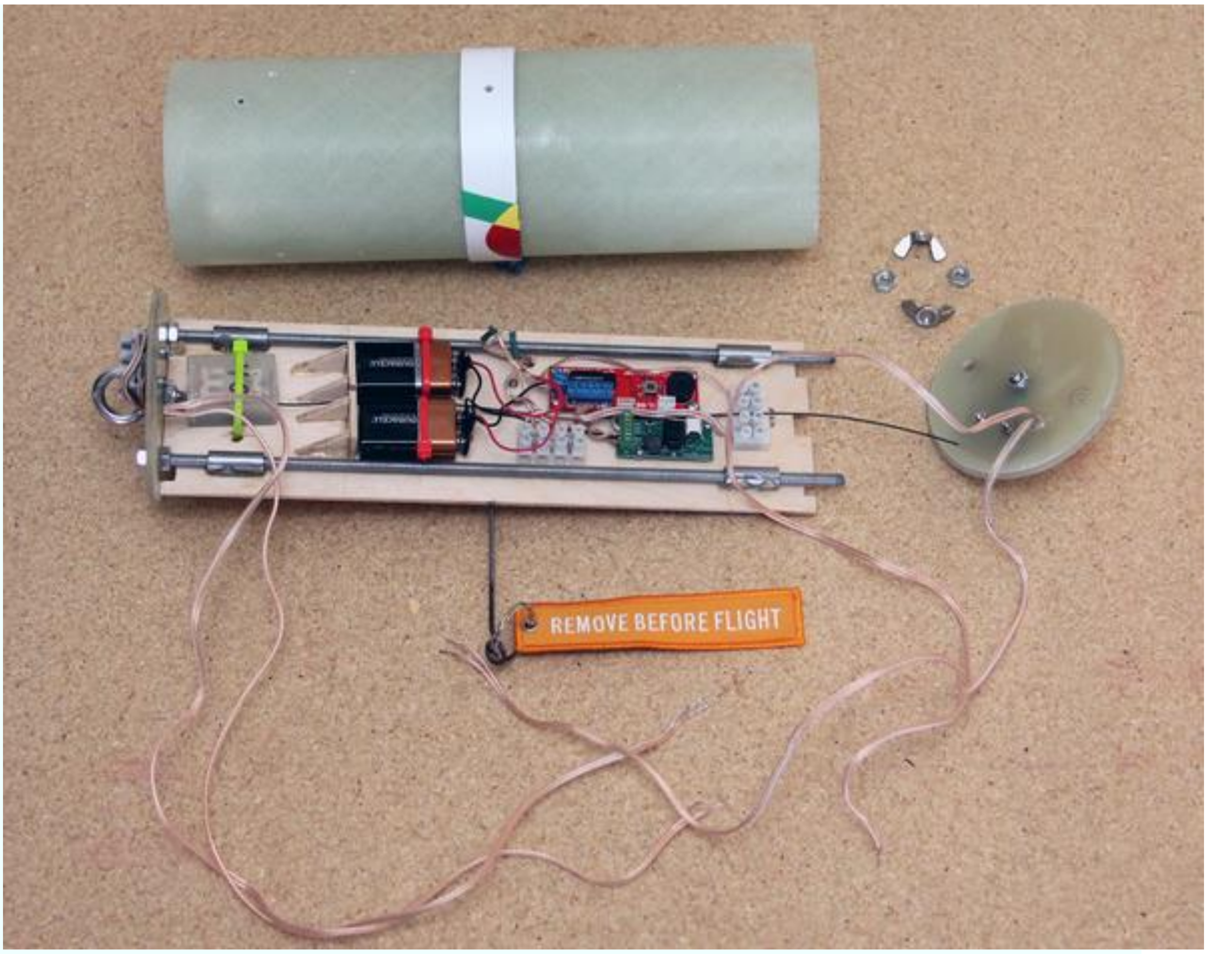


Figure 13-8. The instrument bay, populated with dual flight computers and a tracking radio.

Ejection Charges

The two parachute compartments have rather different sizes, so we'll need to do calculations for two different black powder charge sizes. See "Picking the Size for Recovery Charges" for more detail and background information on choosing the proper amount of black powder.

The booster section, shown in a simplified cutaway view in Figure 13-9, has two compartments containing empty space. The first, approximately 4" in diameter, extends from the base of the electronics bay to the forward centering ring on the motor mount. The second is in the top of the motor tube, extending from the forward end to the top of the motor itself. The distance is approximate, since the top of the motor is a complex shape, but it is close enough for our purposes. For this parachute bay, the volume is:

$$V = \pi \times 10.5 \times 2^2 + \pi \times 5$$

$$V = 163.3\ \text{in}^3$$

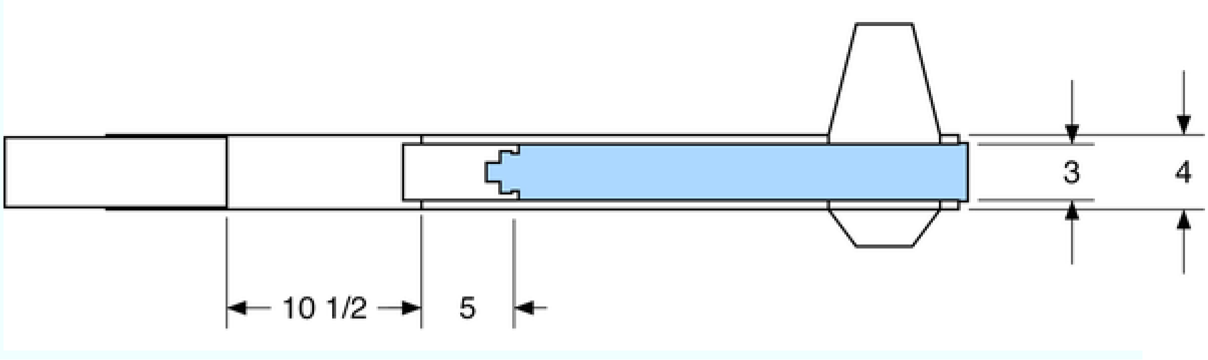


Figure 13-9. Dimensions for the parachute bay in the booster.

The desired mass of 4FG black powder for a chamber this size is:

$$m = \frac{15 \times V}{1939.33}$$

$$m = 1.3\ \text{g}$$

Since the mass of black powder in grams is very close to its volume in cubic centimeters, you can measure this as either 1.3 grams or 1.3 cubic centimeters.

Figure 13-10 shows the relevant dimensions for the forward parachute bay. Approximating the nose cone as a cone rather than an ogive, the calculations work out like this:

$$V = \frac{1}{3}\pi \times 15 \times 2^2 + \pi \times 1$$

$$V = 295.3 \text{ in}^3$$

$$m = \frac{15 \times V}{1939.33}$$

$$m = 2.3 \text{ g}$$

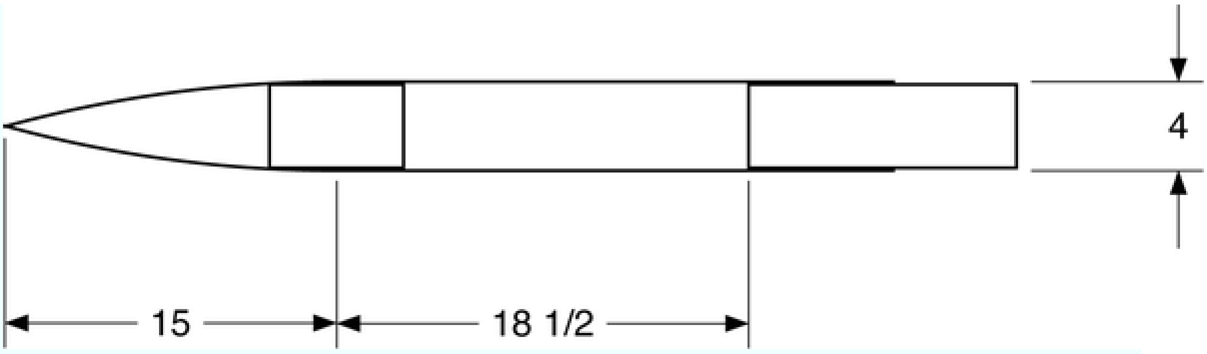


Figure 13-10. Dimensions for the forward parachute bay.

There are lots of ways to pack the charges. Figure 13-11 shows my favorite, with the black powder and igniter stuffed into the finger of a disposable glove. A layer of tape under the charges protects the bulkhead, while a layer of tape over the charges will hold the charges in place during flight. Of course, there is a primary and backup charge, one attached to each flight computer.

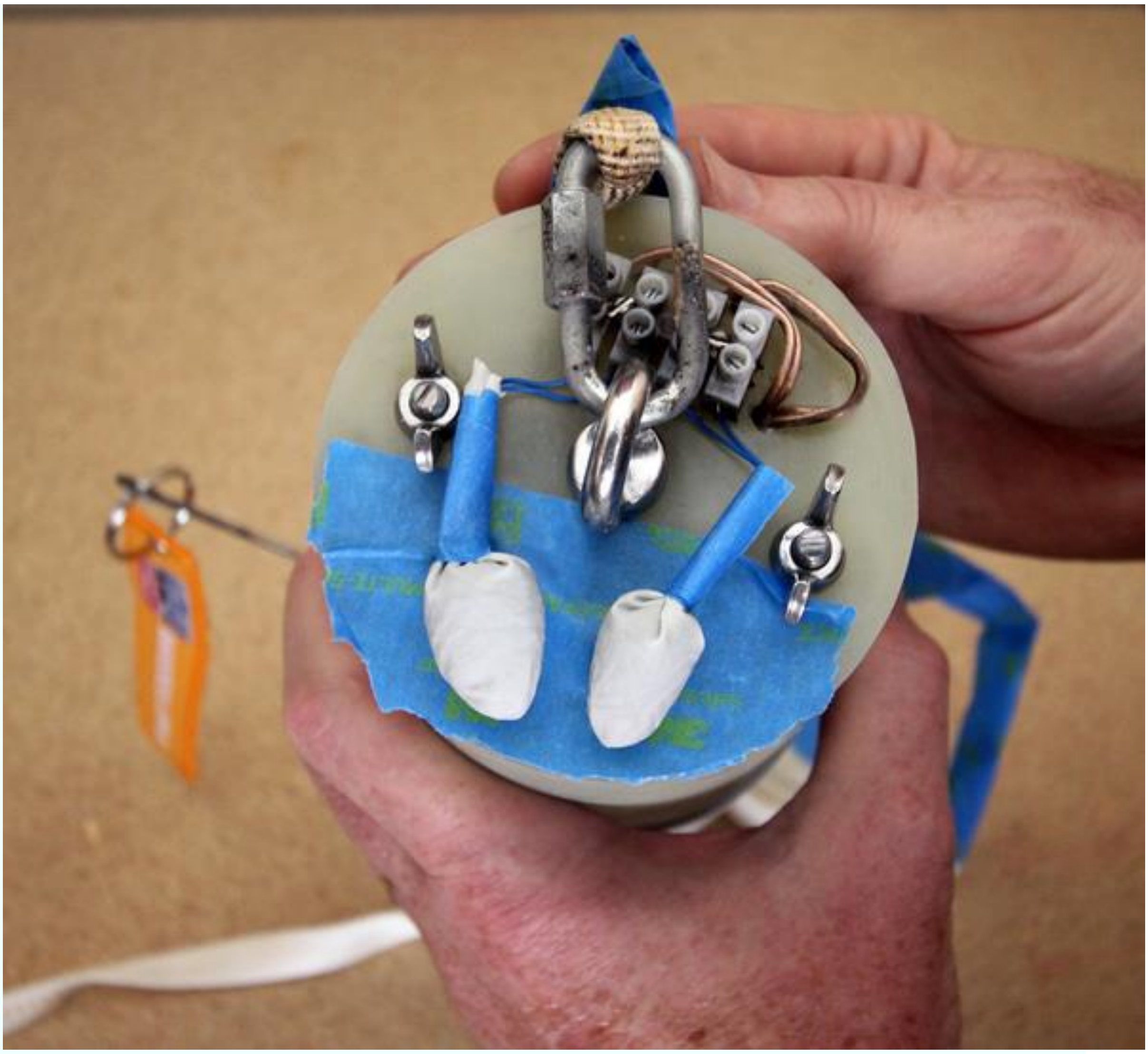


Figure 13-11. Use the finger from a disposable glove to hold the black powder, and tape to protect surfaces and secure the charges.

Doing the math or using a table is an important first step, but you must, of course, do a ground test to verify the charges are the right size. See “Testing Recovery Charges” for thoughts about the ground test.

Selecting Parachutes

The completed rocket, with motor, weighs in at 321 ounces, or a tad over 20 pounds. A full 6 pounds of that weight is rocket fuel, so the weight at recovery drops to 14 pounds. Checking Table 9-1, we see that the drogue parachute should be in the 24- to 36-inch-diameter range. Many fliers don’t use a drogue parachute at all on a rocket like Ganymede, since merely popping the rocket apart into two roughly equal-size tethered tubes causes the rocket to become unstable, increasing the drag significantly. I think that puts too much strain on the main parachute, so I did use a drogue parachute, but I used that reasoning to choose the smaller, 24-inch size.

Table 9-1 doesn’t show parachutes larger than 60 inches in diameter, and that’s not big enough for a main parachute on a 224-ounce rocket. We could do the calculations to find the correct parachute size, but it turns out that it is hard to find a flat parachute larger than 60 inches in diameter, so the calculations don’t help much. There are a lot of possibilities out there, but I opted for the Sky Angle 60” parachute, which has a coefficient of drag of 1.89. The coefficient of drag is based on the circular center of the parachute, which is a 60-inch circle. That works out to an area of 1.82 square meters. Converting the 14-pound weight of the rocket to its metric equivalent, we get 62.2 newtons. That gives all of the values we need to find the velocity from the equation given in “Parachute Aerodynamics”:

$$V = \sqrt{\frac{2\,F_d}{\rho\,A\,C_d}}$$

Plugging in the values, we get:

$$V = \sqrt{\frac{2 \times 62.2}{1.22 \times 1.82 \times 1.89}}$$

$$V = 5.44\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$V = 17.86\,\frac{\mathrm{ft}}{\mathrm{s}}$$

This is right in the middle of the accepted range for speed. Combined with the drogue parachute and the drag from the rocket itself, this will work just fine.

Flying Ganymede

Despite its size, flying Ganymede is really not very different than flying Phobos as a dual-deploy rocket. My own flight was made in Black Rock, Nevada, at BALLS 23. The launch altitude was about 3,600 feet above sea level, and the rocket itself flew either 13,858 feet or 12,577 feet above ground level, depending on which computer you believe. Based on simulations, I suspect the 13,858-foot altitude is closer to the correct mark. That puts the rocket about 17,000 feet above sea level. While that is below the jet stream, it is still high enough that the winds aloft can be very, very different from what you see on the ground. One additional item for your flight preparation is to check the Aviation Weather Center website. This site gives the wind speed and direction at various altitudes. One of our club members did not take this into account on a flight, and also mistakenly ejected the main parachute at altitude. The rocket was found the next day by radio, several miles from the launch point.

The Motor

Other than sheer size, there really isn’t much difference between assembling the motors you’ve already used and assembling a Level 3 motor. Depending on what you have already tried, the one new aspect might be some extra O-rings that go between the fuel grains to make sure there is a separation between them, giving a nice, even burn. The details can also vary from one motor to the next, so we won’t go over motor assembly here. Instead, follow the directions that came with your motor.

Since this is for your Level 3 flight, one of the people on your certification team will want to watch you assemble the motor (see Figure 13-12). It does take some time and a nice clean work area, though. The approach I recommend is to get together with your certifying team a day or two before the flight to assemble the motor. This is a good time for you to ask any last-minute questions, and for them to check your preparations, possibly saving you from an error.

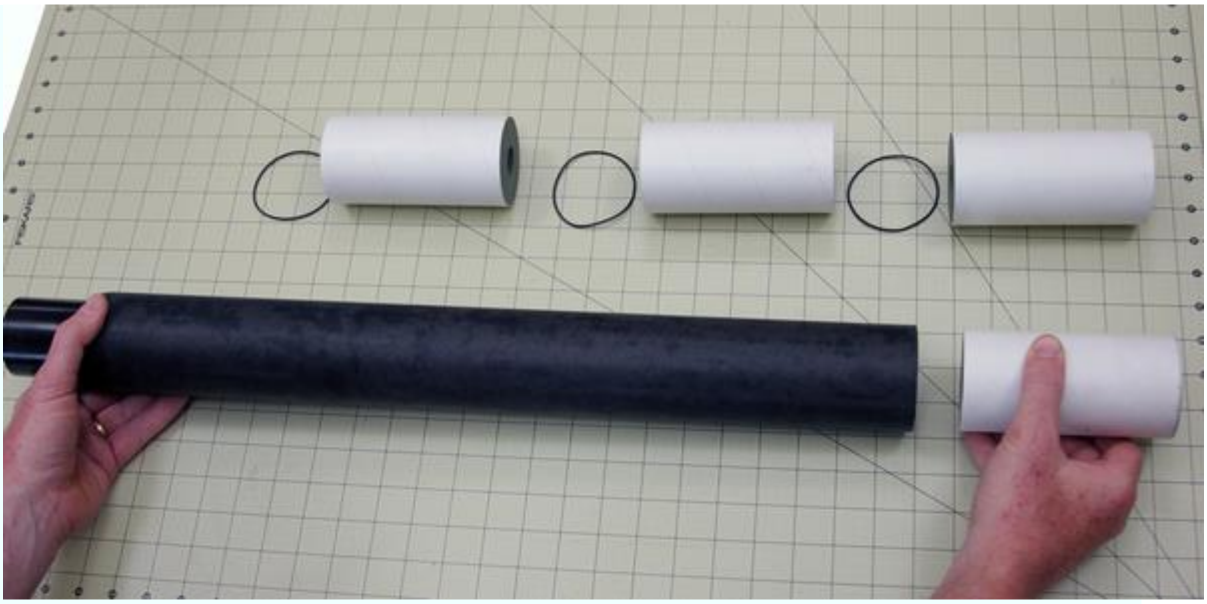


Figure 13-12. Assemble the motor a day or two before the flight, with your certifying team.

There are also some very real differences in the igniters used with a large motor. The most striking is that the motor probably will not come with one. You will need to order a large igniter, and they can be difficult to find. As I write this, Wildman Rocketry sells a package of three igniters with the SKU BIG-UNS-LG-LIGHTERS that will work, but sources change rapidly. Check with your club members for good igniter sources; they may even be able to sell one to you.

The igniter will also be quite long, and it is very difficult to stuff it all the way up into a 24”-long motor. The igniter itself should be taped to a 1/8”-diameter wooden dowel or stick. Use this stick to shove the igniter into place, securing it at the base of the rocket (see Figure 13-13). It may seem odd to leave a sturdy wooden stick inside the motor when it is lit, but the motor will have no problem burning or ejecting the stick as it comes up to full power.

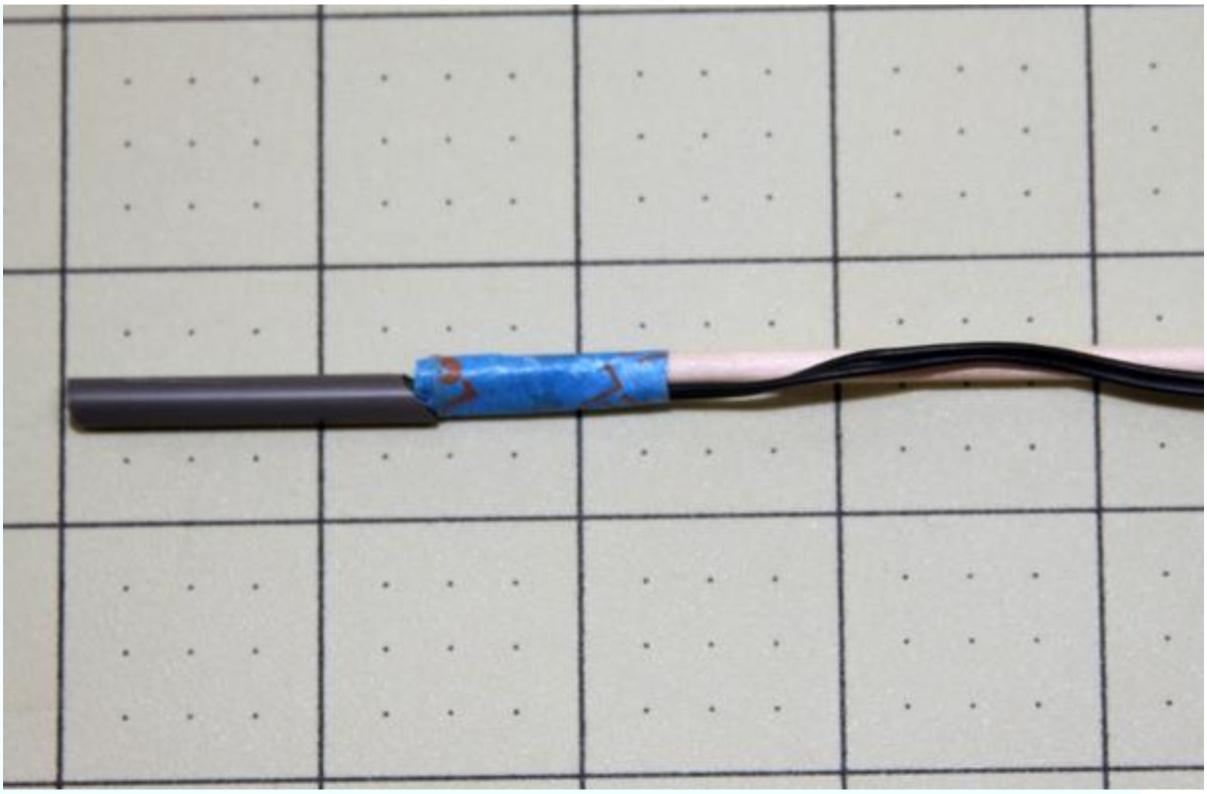


Figure 13-13. Use a 1/8” wooden dowel to insert the igniter into the motor.

WARNING

The dowel used to hold the igniter in place must be thin compared to the size of the opening in the nozzle. The 1/8”-diameter dowel shown here works fine with the AeroTech M1297W. If you are unsure about the rod size, check with more experienced fliers who have used the specific motor you intend to fly.

Checklists

The bigger the rocket, the more important checklists become. In fact, you saw a checklist of checklists back in “Checklists”! Here are the standard prelaunch and launch checklists for Ganymede. You may need to modify them slightly based on your location or design changes, but they are a good start.

Flight Checklists

Prelaunch

1. Connect one shock cord to the motor.
2. Install the motor.
3. Install the tracking device.
4. Connect the altimeter batteries.
5. Assemble the electronics bay.
6. Insert the arming pin to disarm the altimeters.
7. Connect the squibs to the top and bottom terminal blocks.
8. Tape the payload bay and squibs.
9. Roll the drogue parachute in a flame blanket.
10. Attach the drogue parachute to the shock cord.
11. Attach the shock cord to the avionics bay.
12. Insert the electronics bay in the booster. Install the shear pins.
13. Roll the main parachute in a flame blanket.
14. Attach the main parachute to the shock cord.
15. Attach the shock cord to the nose cone and avionics bay.
16. Insert the main parachute bay over the electronics bay. Install the shear pins.

Flight

1. Place the rocket on the pad.
2. Remove the arming pin.
3. Listen for audible confirmation of continuity for the ejection and cable cutter charges.
4. Make sure the launcher is in safe mode.
5. Twist the bare ends of the igniter together.
6. Insert and secure the igniter.
7. Attach the igniter clips, making sure they do not touch.
8. Test for continuity.
9. Check the tracking device.
10. Launch.

Chapter 14. New Heights

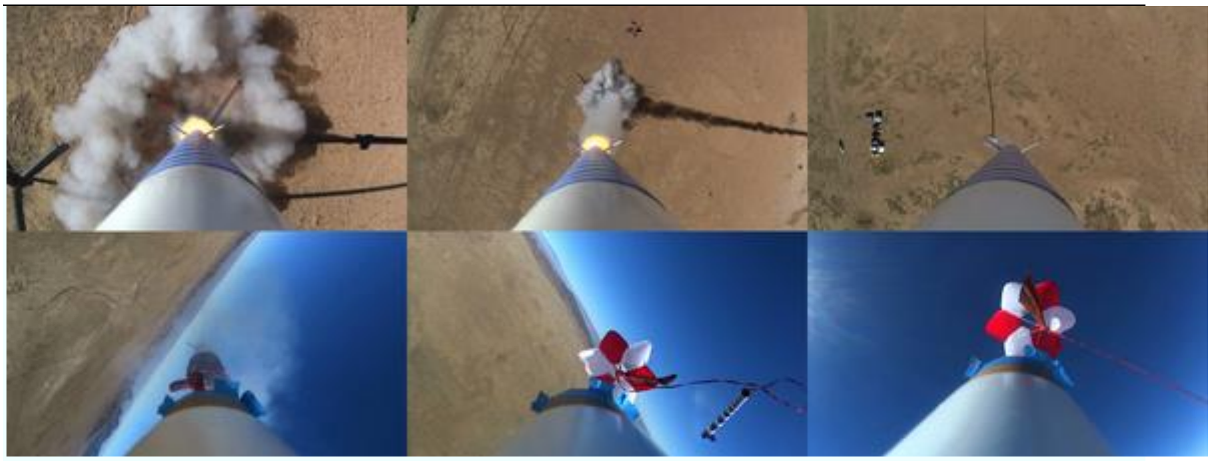


Figure 14-1. A montage of photos from a version of Callisto modified to take a camera.

This book has led you through the challenging process of getting your high-power rocketry certifications. Along the way, you've met a lot of new friends, learned some rocket science, and built some very impressive rockets.

So what's next?

In truth, what comes next depends a lot on your interests. You can learn to build multi-stage or cluster rockets, explore hybrid rockets that use nitrous oxide as a liquid propellant and PVC or some other hydrocarbon as fuel, attach cameras to rockets, perform experiments in transonic flight, or send a rocket to space. Amateur rocket scientists have done all of those things and more.

Figure 14-2. National events are a great place to meet people and buy supplies without all those pesky hazardous materials shipping charges. Here's a part of vendor row at NARAM 56.

National Events

Both NAR and TRA put on several national events around the country. Annual NAR events like the National Sport Launch and NARAM typically cater to both low- and high-power rocketry, making them fun for the entire family. Both of these events change location nearly every year. Check the NAR website for information.

TRA has a similar national event that caters more to high-power rocketry. Like the National Sport Launch and NARAM, Large and Dangerous Rocket Ships (LDRS) is held at different locations each year. Check the TRA website for more information.

Figure 14-3. The flight line at BALLS, where about the only kind of rocket you are unlikely to see is a small one.

Bad Ass Load Lifting Suckers (BALLS) is an annual event held in the fall in a dry lakebed near Black Rock, Nevada. This is the premier event for experimental rocketry. Simply put, experimental rocketry includes rockets that fall outside the guidelines you have followed in this book. This is something TRA supports, but NAR does not, due to the additional safety concerns that go along with these rockets. In some cases, the issue is simply that the rocket is really large, with a total impulse of over 40,960 N-s (the maximum total impulse for an O motor). Another popular activity at BALLS is testing home-built rocket motors.

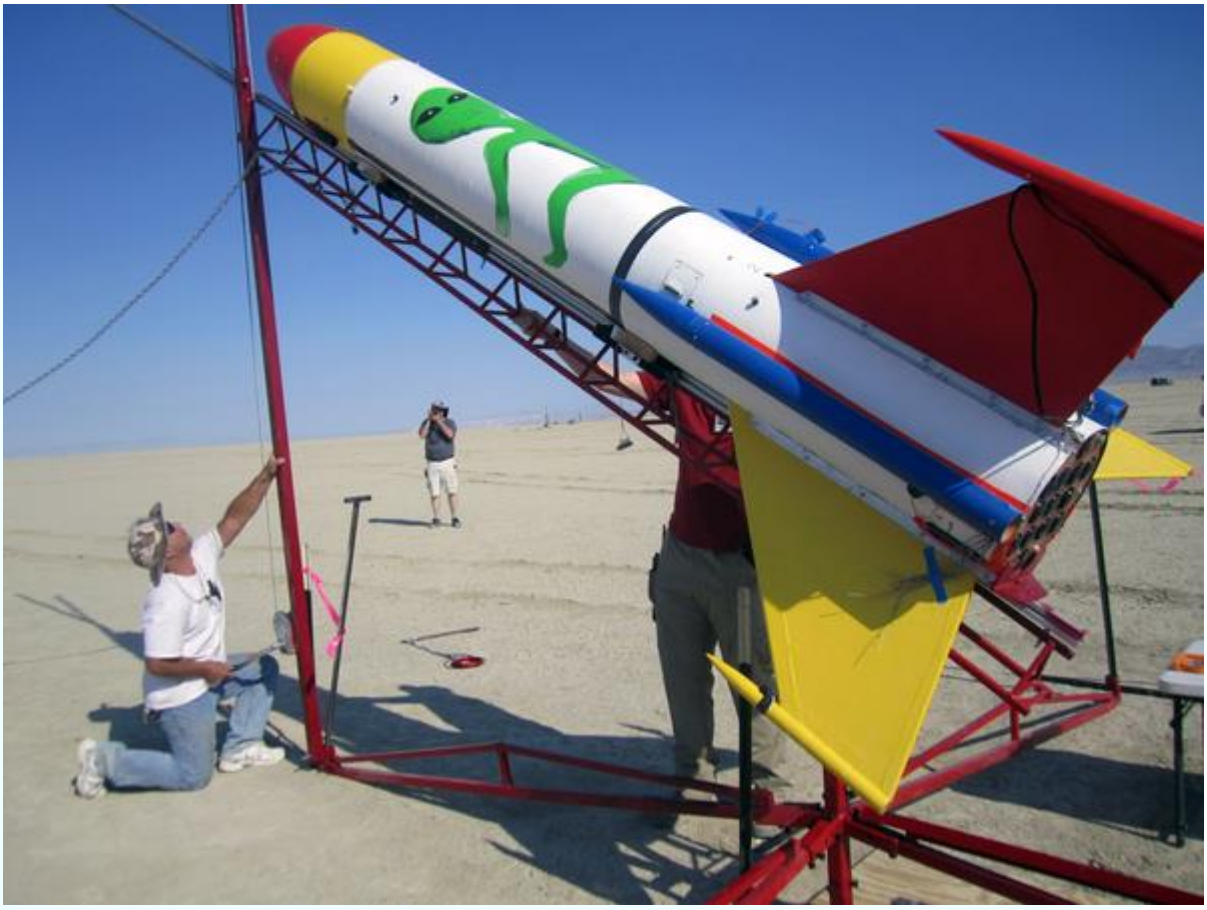


Figure 14-4. Kevin Small guides the nose of the Baby Q as it is lifted onto the launch pad. It sported 13 M motors, giving a total impulse high enough to barely classify it as a Q rocket. Photo by Ken Goldstein.

If you happen to see me at one of these events, or one of the Maker Faires, be sure to stop by and introduce yourself. I’d love to hear about your experiences building and flying the rockets in this book, or whatever other rocket you built to get your certification.

Appendix A. Places to Buy Stuff or Find Information

This appendix lists sources of materials or information you need to make rockets.

Model Rocket Parts and Supplies

Here are some suppliers you'll find useful.

Aero Pack, Inc.

http://aeropack.net/motorretainers.asp

Aero Pack is best known for a full line of motor retainers like the ones seen on every rocket in this book. These are available from many rocket part companies, as well as directly from Aero Pack. They also supply a number of hard-to-find items, like swivels and other recovery hardware, tail cones, and minimum diameter retainers.

AeroTech Consumer Aerospace

http://www.aerotech-rocketry.com

AeroTech manufactures rocket motors and reloads. While the company makes some of its own motors, it actually concentrates more on the reloads for reloadable motors. Many of the motors people refer to as AeroTech reloadable motors were originally built by a partner company called Rouse-Tech, which AeroTechlater acquired.

"Building the AeroTech H128W-M" describes how to prepare and fly one of AeroTech's motors.

Altus Metrum

http://www.altusmetrum.org

Altus Metrum makes a series of altimeters, including the TeleMega 2 with GPS featured in "GPS". Their website has free software and information about their offerings. The altimeters are available through other retailers, such as Apogee Components.

Apogee Components

http://www.apogeerockets.com

Apogee Components sells both low- and high-power rocketry supplies, kits, and motors. They are a great resource for parts and kits and have a fantastic collection of technical reports and how-to guides. When you place a qualifying order, they send you CDs chock-full of them.

Apogee Components also markets RockSim, the most popular rocket simulator for model rocketry.

Balsa Machining Service

http://www.balsamachining.com

Balsa Machining Service has a number of kits and hard-to-find parts, mostly for low-power rocketry. This is also a great place to buy AeroTech motors and reloads.

Cesaroni Technology Incorporated

http://www.cesaroni.net/solidrocket.php

CTI makes rocket motors, both for the high-power rocket community and for professional and military use. Their Pro-X® line of rocket motors appear throughout the book. You can find a detailed tear down of their H163-14A in “Building the Cesaroni H163-14A”.

Estes Industries

http://www.estesrockets.com

The 800-pound gorilla of the low-power model rocket world, Estes Industries has been around since the dawn of model rocketry.

While you might think of Estes as only a low-power rocketry company, their Pro Series line of rockets work quite well with smaller high-power motors. Some of their kits would work well for a Level 1 certification flight.

You can frequently find Estes parts discounted through other retailers like Amazon. Their Pro Series kits are also available from some local retailers.

Featherweight Altimeters LLC

http://www.featherweightaltimeters.com

Featherweight Altimeters makes the Raven altimeter seen in Chapter 7.

Fruity Chutes

https://fruitychutes.com

Fruity Chutes specializes in making parachutes of all sizes, including ones that are rather large. They also have a selection of parachute deployment gear.

Hobby Lobby

http://www.hobbylobby.com

Hobby Lobby is one of the more reliable suppliers of rocketry supplies you are likely to find in your local area. While specialized hobby stores are great, they aren't in smaller cities, and even in large ones they may be fairly far away. Hobby Lobby has a nice selection of rocket motors, launchers, igniters, recovery wadding, and rocket kits. While they mostly cater to low-power rocketry, they do carry the Estes Pro Series, which fly well on small H motors.

Best of all, they frequently offer 40% off coupons for a single item. Do a web search for "hobby lobby 40 off" to find the coupons.

LOC Precision

https://www.locprecision.com

LOC Precision has a great selection of kits and supplies. It is one of the better places to look for heavy fiber (paper) body tubes. While most fliers switch to fiberglass for supersonic flight, these inexpensive, light tubes are great for most high-power rocketry.

LOC Precision was selected as the supplier for Callisto in Chapter 3.

Madcow Rocketry

https://www.madcowrocketry.com

Madcow Rocketry offers a wide selection of kits and parts for high-power rocketry. They have an especially good selection of fiberglass body tubes, couplers, and bulk plates.

Madcow Rocketry was selected as the supplier for Ganymede in Chapter 13.

Missile Works

http://www.missileworks.com

Missile Works specializes in building altimeters, including the RRC3 and RRC2+ that are featured in Chapters 7 and 8. They have a wide selection of rugged altimeters, from budget units through GPS systems.

PerfectFlite

http://www.perfectflite.com

PerfectFlite makes several altimeters, timers, and accessories. Their StratoLogger is shown in Chapter 8.

Prairie Twister Rocketry

http://ptrocketry.blogspot.com

Prairie Twister Rocketry builds and sells the cable cutter used for dual deployment in Chapter 7.

Pratt Hobbies, Inc.

http://pratt-hobbies.com

Pratt Hobbies offers a selection of hobby products that are difficult to find from other sources, like launch controllers, ejection canisters, and the Microbeacon seen in Chapter 10.

Public Missiles Ltd.

https://publicmissiles.com

PML provides a lot of basic rocketry supplies and kits, but they also create a wide selection of custom parts and accessories for high-power rocketry. It’s worth stopping by their site for both the common items and their unique ones.

PML is the supplier selected for Deimos in Chapter 6.

Quest Aerospace

http://www.questaerospace.com

One of the few competitors for Estes in the low-power model rocket arena, Quest has a nice online store featuring motors, parts, and kits. They are frequently less expensive than the Estes parts, and the quality is just as good. Estes has a better selection for most items, though.

Wildman Rocketry

https://www.wildmanrocketry.com

Wildman Rocketry is one of the larger online retailers for high-power rocketry. You can find practically anything you need on their site, from fiberglass parts to motor reloads.

Wildman Rocketry is the supplier selected for Phobos in Chapter 6.

Clubs and Information Websites

Here are some websites for various clubs and other resources.

Author’s Website

http://www.byteworks.us/Byte_Works/Make_Rockets.html

Rocket simulation files for the rockets in this book are available from my website.

OpenRocket

http://openrocket.sourceforge.net

OpenRocket is a free rocket simulator that runs on Linux, macOS, or Windows. It started life as a thesis project. This website is the place to go for downloads, further information, or, if you are a programmer and inclined to help, to join the project team.

Rocket Reviews

http://www.rocketreviews.com

This site is dedicated to customer reviews of rocketry-related products. It’s a good place to browse to find out what is new and what other model rocket scientists think about various products.

The Rocketry Forum

http://www.rocketryforum.com

This is a great place for research and getting your questions answered by experienced model rocket scientists. It’s the next best thing to a 24/7 model rocket club!

ThrustCurve.org

http://www.thrustcurve.org

This site provides thrust curves for most commercially available motors. You can check plots of the thrust curves right on the site, allowing you to pick appropriate motors for a given liftoff weight. You can also download the motor data in common formats suitable for most rocket simulators. These formats use ASCII files to store the data, so you can open the files in any text editor to look at the raw data yourself.

General Supplies and Hardware

These companies can supply you with various tools and other items you'll need.

Ace Hardware

http://www.acehardware.com

Ace Hardware has both an online presence and brick-and-mortar stores in many areas. It's a favorite haunt of mine because of the great selection of nuts, bolts, and other small hardware items, all available in loose bins so you can buy exactly the number of parts you need.

Bolt Depot

http://www.boltdepot.com

This online store specializes in bolts and other fasteners. Look around on their site if you can't find a bolt locally.

Country Brook Design

http://www.countrybrookdesign.com

These folks sell nylon straps in all sorts of sizes and colors. They are a great source when you want to order larger quantities, and tend to be less expensive than other sources.

Home Depot

http://www.homedepot.com

Home Depot is a big-box hardware store that probably has an outlet near you, and also has an online store. It's a good source for general hardware parts like brass, paint, and other supplies.

Lowes

http://www.lowes.com

Lowes is a big-box hardware store, but you can also order online. It’s a good source for brass, paint, and various other supplies.

JoAnn Fabric Store

http://www.joann.com

This is a great place to pick up all sorts of supplies for model rocketry, from cutting boards to elastic for shock cords to nylon for heavy-duty parachutes. JoAnn’s regularly has coupons for 40% off. Check online by searching for “joann coupon” before making your purchase.

OnlineMetals.com

http://www.onlinemetals.com

Some metal parts, like brass tubes, may be difficult to find locally. This online store has a great selection of brass tubes and other metal parts, and they can be ordered in small quantities.

Appendix B. High-Power Rocket Safety Codes

National Association of Rocketry High-Power Rocket Safety Code

The safety code is updated from time to time to reflect lessons learned and changing laws. Please see the NAR website for the latest version of the safety code.

Provided courtesy of the National Association of Rocketry (NAR).

Effective August 2012

1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.
8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at

least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

11. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

Installed total impulse (Newton-seconds)	**Equivalent high power motor type**	**Minimum diameter of cleared area (ft.)**	**Minimum personnel distance (ft.)**	**Mi dis roc**
0–320.00	H or smaller	50	100	20
320.01–640.00	I	50	100	20
640.01–1,280.00	J	50	100	20
1,280.01–2,560.00	K	75	200	30
2,560.01–5,120.00	L	100	300	50
5,120.01–10,240.00	M	125	500	10
10,240.01–20,480.00	N	125	1000	15

Installed total impulse (Newton-seconds)	Equivalent high power motor type	Minimum diameter of cleared area (ft.)	Minimum personnel distance (ft.)	Mi dis roc
20,480.01–40,960.00	O	125	1500	20

Table B-1. Minimum distance table

Note: A complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

Tripoli Rocketry Association Safety Code for High-Power Rocketry

The safety code is updated from time to time to reflect lessons learned and changing laws. Please see the TRA website for the latest version of the safety code.

Provided courtesy of Tripoli Rocketry Association (TRA).

This High-Power Rocketry Safety Code is the product of many years of effort on behalf of the hobby by those who care about it and whose prime interest is safety. This document sets minimum standards, intended to preserve the hobby in a safe environment. Using this Code as the minimum, it will be your responsibility to regulate your own launches safely for the conditions of each launch site. This Safety Code shall be the standard at all Tripoli Sanctioned Launches.

The Tripoli High-Power Safety Code ***supplements*** **NFPA 1127 Code for High-Power Rocketry** with sections that are specific to Tripoli. The foundation of the Tripoli High-Power Safety Code is NFPA 1127.

- **1 General Requirements**
    - **1-1 Scope**
        - **1-1.1** This code shall set practices for safe operation of High Power rocket launches. It will also address

some aspects of safe rocket design, and construction, and limitations of motor power, for use by the certified user for the purposes of education, recreation and sporting use.

- **1-2 Purpose**
    - **1-2.1** The purpose of this code shall be to establish guidelines for reasonably safe operation of rockets at Tripoli Sanctioned Launches.
- **1-3 Definitions:**

- For the purposes of this code, the following terms shall be defined as stated in this section. Some of these may be redundant from NFPA 1127.
- **Insured Flier:** A flier that has insurance provided by Tripoli or any rocketry organization that TRA has insurance reciprocity with. At this writing this includes NAR only. Note: some types of TRA membership do not include insurance (e.g. Associate, and Honorary members).
- **Adult Flier:** An *Insured Flier* that is 18 years old or older.
- **High Power Rocketry Flier (HPR Flier):** An *Adult Flier* that is certified to fly High Power rockets at their certification level.
- **Model Rocket Fliers (MR Flier):** An Insured Flier who is not certified to fly High Power rockets.
- **Invited Guests of Fliers (Guests):** A person who is not a member of a recognized rocketry organization/not covered by insurance.
- **Launch Director (LD):** A Level 2 or Level 3 flier who has overall administrative responsibility for the launch.
- **Participants.** Persons that are either:
    - **HPR Fliers.**
    - **Model Rocket Fliers.**
    - **Invited Guests of Fliers.**
- **Range Safety Officer (RSO).** A Level 2 or Level 3 flier who has the authority to ensure the safe operation of the range.
- **Sanctioned Launch.** A sanctioned launch is a ***Tripoli Insured Launch***. Any *Sanctioned Launch* shall meet ***ALL*** of the following requirements:

    - Responsible person of launch shall be member of Tripoli in good standing.
    - Follows the appropriate Tripoli Safety Code.
    - All AHJ (e.g. FAA waiver) requirements/regulations met and any required permits secured.
    - Landowner permission has been formally obtained.
- **Shall.** Indicates a mandatory requirement.
- **Should.** Indicates a recommendation or that which is advised but not required.
- **Spectator.** A nonparticipant whose primary purpose is to view a rocket launch.
- **Spectator Area.** An area designated where spectators view a rocket launch.
- **Tripoli Mentoring Program (TMP).** Program to permit Tripoli Junior members to participate in supervised high power rocketry activities.
- **Tripoli (TRA).** Tripoli Rocketry Association, Inc.

Requirements for High Power Rocket Operation

- **2 Operating Clearances.** A person shall fly a high-power rocket only in compliance with:
    - This code and NFPA 1127;
    - *Federal Aviation Administration Regulations*, Part 101 (Section 307,72 Statute 749, Title 49 United States Code, Section 1348, “Airspace Control and Facilities,” Federal Aviation Act of 1958);
    - Other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.
    - Landowner permission.
- **3 Legality**
    - **3-1** The Tripoli Rocketry Association does not claim Rocketry to be legal in every municipality, state or political jurisdiction.
- **4 Insurance**
    - **4-1** Tripoli rocketry activities are only insured when the provisions of this code are followed.

    - **4-2** No Tripoli member shall misrepresent to any authority or landowner that Tripoli activities are insured.
- **5 Participation,**
- *Participation Note: The information provided below identifies the minimum requirements for individuals that participate/attend Tripoli Sanctioned Launches.*
- A Launch Director has the authority to impose more stringent rules.
- **Participation and Access at Tripoli Launches shall be limited to the following:**
    - **5-1** HPR Fliers may access and conduct flights from the High-Power Launch Area and/or Model Rocket Launch Area.
    - **5-2** Non-Tripoli Members age 18 and over who are students of an accredited educational institution may participate in joint projects with Tripoli members.
        - **5-2.1** These individuals are only allowed in the High-Power Launch Area while supervised by an HPR Flier.
        - **5-2.2** They are only allowed in the Model Rocket Launch Area while supervised by an Adult Flier.
        - **5-2.3** The maximum number of nonmember participants shall not exceed five (5) per supervising flier.
    - **5-3** Tripoli Junior Members who have successfully completed the TMP may access and conduct flights from the High-Power Launch Area while under the direct supervision of a Tripoli HPR Flier in accordance with the rules of the TMP.
        - **5-3.1** The maximum number of TMP participants shall not exceed five (5) per supervising flier.
    - **5-4** Children younger than 18 years of age may conduct flights from the Model Rocket Launch Area under the direction of an Adult Flier.
    - **5-5** An invited guest may be permitted in the Model Rocket Launch Area and preparation areas upon approval of the RSO. Invited guests are not permitted in the High-Power Launch Area.

    - **5-6** Spectators are only permitted in the spectator area(s); they are not permitted in the High- Power Launch Area or Model Rocket Launch Area.
- **6** Tripoli Launch Operations
    - **6-1** Insured Fliers shall provide proof of membership and certification status upon request.
    - **6-2** All flights and static motor tests conducted by a member shall be within the member's certification level, with the exception of permitted certification attempts.
    - **6-3** When three or more rockets are to be launched simultaneously, the minimum spectator and participant distance shall be the value set forth in the Safe Distance Table for a complex rocket with the same total installed impulse, but not more than 610 m (2000 ft), or 1.5 times the highest altitude expected to be reached by any of the rockets, whichever is less.
    - **6-4** No range activity shall be conducted when a thunderstorm has been reported within ten miles, or less, of the launch site or if thunder or lightning is present.
    - **6-5** No rockets shall be launched when the surface winds exceed 20 MPH (32 KPH)
    - **6-6** The minimum safe standoff distance from the spectator area for the Model Rocket Launch Area shall be 50 feet (15 meters).
    - **6-7** All flights planned to exceed 50,000ft AGL shall be submitted to the Class 3 review Committee for approval.
    - **6-8** Launch Director and Range Safety Officer
        - **6-8.1** The LD or RSO may refuse to allow the launch, or static testing, of any rocket or rocket motor that they deem to be unsafe.
        - **6-8.2** The LD or RSO may require greater Safe Standoff Distances than specified in this code.
    - **6-9** Recovery
        - **6-9.1** A rocket shall be launched only if it contains a recovery system that is designed to return all parts of the rocket to the ground safely.
        - **6-9.2** Rockets that employ passive recovery (e.g. tumble recovery, aero-braking) need not employ an active recovery system.

Minimum spectator and Participant Safe Distance Standoffs

Total Installed Impulse, N-s		Motor type	Non-Complex feet	meters
0.01 to	160	High Power G or smaller	100	30
160.01	320	H	100	30
320.01	640	I	100	30
640.01	1280	J	100	30
1,280.01 to	2,560	K	200	61
2,560.01 to	5,120	L	300	92
5,120.01 to	10,240	M	500	153
10,240.01 to	20,480	N	1,000	305
20,480.01 to	40,960	O	1,500	457

- **7 Referenced Publications**
- The following documents or portions thereof are referenced within this code. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.
  - **7-1 NFPA Publications.**
  - National Fire Protection Association, 1 Batterymarch Park, P.O. Box *9101*, *Quincy*, *MA 02269-9101*
  - NFPA 1122, Code for Model Rocketry.

    - NFPA 1125, Code for the Manufacture of Model Rocket Motors.
    - NFPA 1127, Code for High Power Rocketry
    - **7-2 Government Publications.**
    - Superintendent of Documents, U.S. Government Printing Office, Washington DC 20402.
    - Federal Aviation Administration Regulations, from the Code of Federal Regulations.
    - Federal Hazardous Substances Act, from the United States Code (re. Airspace Control)
    - **7-3 TRA Publications.**
    - Tripoli Rocketry Association, Inc., P. O. Box 87, Bellevue NE 68005.
    - Articles of Incorporation and Bylaws
    - Tripoli Motor Testing Committee (TMT), Testing Policies
- **Appendix A - Additional Tripoli Rulings**
- **A-1** NFPA 1127 was adopted by the Tripoli Board of Directors as the Tripoli Safety Code. (*Tripoli Report*, April 1994, Tripoli Board Minutes, New Orleans, 21 January 1994, Motion 13.)
- **A-2** All Tripoli members who participate in Association activities shall follow the Tripoli Certification Standards.
- **A-3** Any Board action(s) with regard to safety, made previous to or after publication of this document, shall be a part of the Tripoli Safety Code.
- **A-4** Increased descent rates for rocket activities conducted at the Black Rock Desert venue are acceptable if needed to insure a controlled descent to remain inside the FAA approved Dispersion Area.
- **A-5** A rocket motor shall not be ignited by using:
    - a. A switch that uses mercury.
    - b. “Pressure roller” switches

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e or in part without written permission is prohibited.

Glossary

aft closure

Reloadable motors are typically made from three reusable parts and several disposable parts. The metal case has two threaded parts. The aft closure is the part that screws into the rear of the motor, holding the nozzle in place. See also *forward closure*.

aileron

The control surface on a wing or wing-like fin.

air rocket

Air rockets are propelled by a blast of pressurized air from the launcher. They can be pretty simple (such as a soda straw rocket) or very complicated (like an air rocket glider).

airfoil

The shape of the cross section of a wing or other flying surface. In model rocketry, airfoil also refers to the shape of a fin that is streamlined to reduce drag.

airframe tube

A body tube used as the main airframe for a rocket.

altimeter

A small device, usually but not always electronic, for measuring the altitude of a rocket.

ammonium perchlorate

A rocket fuel used in many high-performance rockets. It was used in the solid boosters for the Space Shuttle. It is also the most common fuel for high-power model rocketry.

amp

An abbreviation for ampere, a unit of electric power. One ampere is 6.241×10^{18} electrons flowing past a point per second.

angle of attack

The angle between a flight surface and the direction of flight. For a fin, this is the angle between the flat surface of the fin and the wind direction. For almost any rocket, it's the angle between the body tube and the wind. For a glider, each flight surface is usually looked at separately, although you can also look at the angle between the nominal direction of flight for the glider and the direction of the wind.

APCP

Ammonium perchlorate composite propellant. See *ammonium perchlorate*.

aphelion

The point in an orbit when a body is farthest away from the Sun. Compare this to apogee.

apogee

Technically the point in an orbit when a satellite is farthest from the Earth, this term is used in model rocketry to describe the highest point in the rocket's flight.

apogee event

The event that occurs when the rocket reaches apogee, generally ejecting a parachute or streamer.

arming key

A mechanism to disable the electrical ignition system. This is called the arming key, even if it happens to be a plug or switch.

aspect ratio

The square of the span of a fin divided by the area of the fin.

astronomical unit (AU)

The astronomical unit, abbreviated AU, is a unit for measuring distances in the solar system. One AU is the average distance from the Sun to the Earth.

axial deployment

Describes recovery system deployment along the axis of the rocket, where the parachute or streamer generally pops out of the body tube, pushing the nose cone off in the process. See also *side deployment*.

azimuth angle

The angle along the horizon from a reference point to an object. See also *theodolite*.

ballistic return

A rocket falling the same way it flew, nose first and streamlined. Unsafe unless the rocket is very light compared to its size.

BALLS

The annual research launch for TRA, Bad Ass Load Lifting Suckers (BALLS) is held each year in Black Rock, Nevada.

balsa

A tropical tree famous for its lightweight wood. Pound for pound, it’s stronger than steel! Balsa wood is available from many hobby and craft stores in blocks and planks. It is commonly used in model rocketry for nose cones, nose blocks, fins, and glider wings.

barometer

An instrument used to measure air pressure.

base drag

The drag created by the flat rear end of the rocket.

baseline

The distance from the rocket launcher to an altitude tracker, or the distance between two altitude trackers.

Bates grain

A rocket fuel configuration consisting of multiple cylinders of center-burning fuel pellets that gives a fairly even thrust curve.

black powder

Also called gunpowder, this is a flammable substance used for rocket fuel in most low-power model rockets, and a few mid- and high-power rockets.

blast deflector plate

The part of the launcher that deflects the hot exhaust from a rocket motor so it does not scorch the launcher or the ground.

boat tail

A transition piece that gradually reduces the diameter of a rocket, typically used at the base of a rocket to reduce base drag or below a fat payload bay to reduce drag from the payload bay.

body tube

The long cylinder that forms the main structure of most rockets. Not all rockets have a body tube, of course.

booster motor

The first stage of a two-stage rocket, or an intermediate stage of a multi-stage rocket. Usually designed to ignite the motor for the subsequent stage with no ejection delay or ejection charge. Booster motors have a zero for the delay time in their designation; a C6-0 motor is a booster motor.

boundary layer

When an object is moving through a fluid, the fluid right next to the object moves right along with the object. A short distance away, the fluid barely moves at all. The layer of fluid between the skin of the object moving through the fluid and the part of the fluid that doesn’t move much is called the boundary layer.

bulk plate

A disk that forms a barrier across a body tube. Also called a bulkhead.

bulkhead

Also called a bulk plate, this is a plate that extends across a body tube, blocking the volume above and below the bulkhead.

buntline knot

A good knot for tying shock cords to screw eyes, or any other situation where a string or rope is fastened to a fixed rod or loop.

burn rate

The rate at which rocket fuel burns, measured in distance divided by time.

burrito fold

The southwestern favorite method to roll a parachute in a recovery blanket.

CA glue

Cyanoacrylate glue, also known as super glue, is a strong, fast-drying glue. In a thin form, it’s used to strengthen porous parts, since it soaks into the part before drying. Thicker forms are great for gluing porous parts.

cable cutter

A device used to cut a cable. A typical use is cutting a zip tie that holds a parachute closed; this can be used to implement dual deployment on rockets that only have one parachute bay.

caliber

In model rocketry, the ratio of the distance between the center of pressure and the center of gravity to the diameter of the rocket. If the rocket is 1” in diameter, and the distance from the center of pressure to the center of gravity is 2”, the rocket has a caliber of 2.

CATO

A slang term for a catastrophic failure; typically a rocket motor that explodes, burns through the motor wall, or comes apart during combustion.

center of gravity

The point a body turns around when rotating, given no other forces are acting on it.

center of pressure

The point where pressure from the wind is the same on either side of the point. An object held in the wind at its center of pressure will not rotate.

centering ring

A disk or short cylinder used to mount one tube inside another. In model rocketry, centering rings are typically made from paper or wood. They have many uses, the most common of which is to mount a motor tube in a larger body tube.

chamfer

Technically a beveled edge between two surfaces, in model rocketry *chamfer* is often used as a verb describing the process of removing a beveled protrusion left when tubes are cut.

chord

In aerodynamics, the chord is the length of a fin or wing from front to back, measured in the direction of air flow.

closed track

When tracking with two theodolites, it’s possible for the altitude reported by the two trackers to differ. Under NAR contest rules, if the difference in altitude is less than 10% of the altitude, the altitude measurement is called a closed track, and the result is considered valid. The altitude used is the average of the altitudes reported by the two theodolites. See also *open track*.

cluster rocket

A rocket with two or more motors on the same stage.

coefficient of drag

A number that accounts for the shape of an object in the equation for drag.

complex rocket

Any rocket with more than one motor—i.e., any rocket with more than one stage or with clustered motors.

composite motor

In model rocketry, generally a motor that uses ammonium perchlorate as the primary fuel, as opposed to black powder.

computational fluid dynamics

Often abbreviated CFD, this is the overall term used to describe computer codes that calculate how fluids and gases flow over objects. Some CFD codes can be used to simulate air flow over a rocket.

control horn

A small projection from a flight surface or a device mounted on a motor or rod to translate movement. For example, a control horn on a servo might be a projection that turns with the motor, allowing the turning motion of the motor to be changed to a push–pull motion. A control horn on an aircraft elevator allows a push–pull motion to rotate the control surface up or down.

Darwin Awards

Humorous awards given to people who remove themselves from the gene pool in particularly creative ways.

datum

An arbitrary starting point used, among other things, to calculate the center of gravity of a rocket.

Delay Adjustment Tool (DAT)

A device used to change the delay times for Cesaroni reloadable motors.

delay charge

A smoke charge that burns after the rocket propellant is exhausted, providing a delay and usually a smoke trail until the rocket reaches apogee and the ejection charge fires.

delay time

The time between the end of the thrust phase of a rocket and the firing of the ejection charge. The delay time is part of the motor designation. For example, a B6-4 motor has a 4-second delay time.

density

The ratio of mass to volume. The density of air is the mass of the air divided by the volume of the air.

dihedral

In aircraft, the angle between the wing and the horizontal flight plane.

drag

The force on a model rocket caused by pushing through air. It acts in the opposite direction from the direction of travel of the rocket.

drag separation

Technically the separation of parts of a rocket due to drag, such as when the booster has a much higher drag than the payload, causing it to be pulled off as the rocket coasts. The term is often applied to a rocket that separates due to pressure building up inside it, since the two causes are difficult to distinguish after the fact.

drogue event

The event used to eject the drogue parachute. This is often the same event as the apogee event.

drogue parachute

A small parachute, usually ejected at apogee, used to slow the rocket down so the main parachute can open without tearing.

dry fit

The practice of fitting parts together without glue to make sure the fit is correct. Glue is applied once the pieces fit well.

dual battery

Some flight computers can accommodate two batteries, one used to power the device and the other used to light ejection charges or rocket motors.

dual deploy

The term used to describe a two-stage recovery process. Generally, a drogue parachute is ejected at apogee, and a main parachute is ejected close to the ground, although there are variations to this theme.

duck tape

Duck tape is a cloth-based waterproof tape. Invented during World War II, it was used by soldiers to tape ammunition boxes shut, giving them a waterproof seal. This earned the tape the affectionate name of duck tape, which stuck. Occasionally, people who are unaware of the origins of the name refer to it as duct tape.

dynamic stability

Dynamic stability refers to the stability of the rocket as it moves, analyzed separately from just looking at whether the rocket will tumble. This is particularly important in understanding weathercocking, where a rocket might be stable, but could still fly in unpredictable directions because of the combination of its stability, the wind, and the speed of the rocket. See also *static stability*.

e-match

A common kind of igniter used to light ejection charges and motors that have built-in Pyrodex charges.

elevation angle

The angle between the horizon and an object. See also *theodolite*.

elliptical nose cone

A nose cone whose cross section is a mathematical curve called an ellipse.

end cap

The base of a hollow nose cone that is all or partly closed at the bottom.

engine block

A device inserted in the motor tube to prevent the motor from moving forward. This is usually a small paper or fiber ring glued firmly into the body tube, but with a hole to allow the ejection charge to pass through.

ejection charge

A small black powder charge generally used to eject the parachute. The ejection charge fires after the motor finishes the thrust phase and coasts to apogee.

ejection delay

The time between the end of thrust from the motor and firing the ejection charge.

engine hook

Used to hold a rocket motor firmly in place during flight. Usually made from small, flat pieces of steel, engine hooks also make it easy to remove and insert motors.

epoxy glue

Epoxy resins are mixed just before use. Rather than drying to form a bond, like wood glue or CA glue, epoxy bonds due to a chemical reaction between the two components that are mixed just before the glue is used. It is very strong and will set and dry even when the parts are not exposed to air.

equilibrium

In terms of stability, equilibrium is when something is not moving away from its current state. For a rocket, this generally means the nose is pointed in the direction of flight, although technically it could be pointed in any direction, as long as it isn't flipping about. See *stable equilibrium* and *unstable equilibrium*.

fablab

See *makerspace*.

featherweight recovery

Rockets that are extremely light compared to their size can use featherweight recovery, where the rocket may return ballistically, but is so light it will not damage itself or anything it hits.

fillet

A narrow strip of glue added to a joint to increase the strength of the joint. These are often applied by running a bead of glue along the joint, then wiping your finger across the bead to make it smooth and regular.

fin

A small projection near the base of the rocket used to make the rocket stable. Feathers on an arrow are fins, for example.

fin cant

A tilt in the fin relative to the direction of motion that causes the rocket to spin.

fin height

The distance from the body tube to the part of the fin farthest from the body tube.

fin root

The part of a fin that attaches to the body tube.

fin rotation

The amount a fin is rotated about the body tube centerline. Fin rotation is used to position fins in a rocket simulator.

fin tab

In a through-the-wall fin, the part of the fin that is inside the outer body tube. Also called the tang.

fineness ratio

The ratio of the length of a nose cone to the diameter of the body tube. A 3”-long nose cone on a 1”-diameter body tube has a fineness ratio of 3.

first stage

The initial stage in a multi-stage rocket.

flame blanket

See *parachute protector*.

flash

The excess plastic squeezed into the crack between segments of a multipart mold. In model rocketry, usually found on things like nose cones.

flashing

Loading software into the nonvolatile memory of a microcontroller.

flight computer

The device used to track the progress of the flight, initiating events like the apogee event and main event. Also called the altimeter, since that is the primary sensor used to control events.

fluid flow

The way objects move through liquids and gases.

form drag

Another name for pressure drag.

forward closure

Reloadable motors are typically made from three reusable parts and several disposable parts. The metal case has two threaded parts. The forward closure is the part that screws into the front of the motor, either to block the front end or to hold the ejection charge. See also *aft closure*.

friction

A force that acts in the opposite direction of motion or in the opposite direction of a propulsive force. Friction is what makes things stop—without friction or some other force, a moving object would keep moving indefinitely.

friction drag

The component of drag caused by the viscous effects of the fluid or gas through which the object is moving.

friction fit

In rocketry, the art of holding a motor in place in a minimum diameter rocket by wrapping tape around the motor until it fits very tightly. This is only used so the ejection charge ejects the parachute or streamer instead of the motor. An engine block is used to prevent the motor from sliding forward in the rocket.

frontal area

In the drag equation, the frontal area is a representative area used to account for the size of the object. In model rocketry, this is the area of the cross section of the largest body tube plus the fins and launch lug.

fuselage

The body of an airplane.

grain

Cylindrical pellets of fuel used in reloadable motors.

Haack series nose cone

A nose cone with a profile defined by a mathematical shape known as a Haack series. See also *Von Kárman nose cone*.

hackerspace

See *makerspace*.

heat shrink tubing

A thin, insulated tube of plastic that will shrink when exposed to heat, usually supplied from a specialized heat blower. It is used to create an insulated cover on electric wiring.

high-power model rocketry

Flying a rocket that requires FAA clearance before flights, but that is small enough not to require FAA approval of the individual rocket and flight. While there are a couple of exceptions, this typically includes rockets that use motors in the H to O class.

hobby knife

A cutting instrument with a blade that can be easily replaced when it becomes worn. X-ACTO makes the most widely available hobby knives, which can be found in almost any hobby or craft store.

hybrid motor

A rocket motor that uses fuel in two different physical states. The most common hybrid motor in rocketry uses nitrous oxide in a liquid state as an oxidizer and a solid fuel, often rubber or PVC.

igniter

A device used to start combustion in a rocket motor, and sometimes to fire pyrotechnic charges to eject parachutes or deploy other recovery devices. All igniters in model rocketry are triggered by electricity.

igniter clips

Small clips used to connect the launcher’s wire to the igniter in the rocket motor.

imperial units

The system of units commonly used in the United States; units like inches, pounds, and seconds.

impulse

The force exerted by a rocket motor over a given time, usually measured in newton-seconds, where one newton is one kilogram-meter/second^2. Impulse is also frequently measured in pound-seconds.

induced drag

When a fin or wing produces lift, either to lift an airplane or to rotate a rocket back to straight flight, some air slips over the tip of the fin or wing. This forms a vortex, spinning air that contributes to the drag on the rocket or airplane. This drag is called induced drag.

inertial forces

In fluid flow, the forces from the molecules of the fluid bumping into an object. The ratio of inertial force to viscous force is the Reynolds number.

internal resistance

The resistance exhibited by a battery when used in a circuit.

joule

A unit of energy, equivalent to the kinetic energy of a one-half-kilogram mass moving at one meter per second. The units are kilogram-meter^2/second^2.

kinetic energy

The energy of a body in motion. Kinetic energy is equal to 1/2 $m v^2$, where m is the mass of the object and v is the speed at which it is traveling.

laminar flow

The smooth flow of a fluid past an object with very little if any turbulence. See *turbulent flow*.

land shark

A rocket that turns sideways just after launch and flies more or less horizontally. This can be caused by a marginally stable rocket, a rocket that isn’t traveling fast enough when it reaches the end of the launch rail, or a structural failure.

launch cable

The wire that runs from the launch controller to the launch pad.

Launch Control Officer (LCO)

The person who directs the setup, organization, and operations at the launch site.

launch controller

The electrical ignition system used to ignite the rocket motor.

launch key

A plug or an actual key used to enable the launch system.

launch lug

Attaches a rocket to a rod or rail to guide it for the first few feet of flight. Typically made from thin tubes for launch rods or button-shaped tabs for launch rails.

launch pad

The structure that holds the launch rod, providing a stable launch mechanism for the rocket. Sometimes the term is used to include the launch controller, too.

launch rod

Guides a rocket for the first few feet of flight. Sometimes a launch rail is used instead.

Launch Safety Officer (LSO)

Another name for the Range Safety Officer (RSO). See *Range Safety Officer*.

law of sines

For a triangle, the ratio of the length of the side opposite the angle and the sine of the angle is a constant for all three combinations of angles and sides.

lawn dart

A rocket that has arced over and returns to earth in a nose-first ballistic trajectory, without a working recovery system.

LCO

Launch Control Officer.

LDRS

The annual TRA meet, Large and Dangerous Rocket Ships (LDRS) includes high-power launches and competitions, like the Odd Rocks competition.

leading edge

The part of the rocket that hits the air first, usually used when referring to a fin or wing. The leading edge of the fin, for example, is the edge closest to the nose cone.

low-power model rocketry

For the purpose of this book, low-power rockets are those that use E or smaller motors and weigh one pound or less.

low Reynolds number airfoil

An airfoil designed for small wings. Under these conditions, the Reynolds number is still high compared to that of, say, a ship going through water, but it is lower than the Reynolds number for most wings.

LSO

Launch Safety Officer.

Mach number

The speed as a fraction of the speed of sound. Mach 1.0 is the speed of sound, while Mach 2.0 is twice the speed of sound.

main event

The event where the main parachute is ejected. This term is generally only used for dual-deploy flights.

makerspace

A cooperative shop where hobbyists can use facilities and tools purchased and maintained by the group. Classes and group projects are common. Also called a fablab or hackerspace.

mass drive

A concept proposed as a cheap way to launch material, especially from an airless body like the Moon. The mass drive fires the material from a ground propulsion system. It is then snagged in orbit or continues to propel itself with onboard rockets.

metric units

Used in virtually every country except the United States, and used extensively in science and engineering in the United States: in units like meters, kilograms, and seconds. The metric system is technically known as the International System of Units, and is abbreviated as SI for the name of the standard in French, or MKS, which is short for meters-kilograms-seconds.

microcontroller

A small self-contained computer containing a central processing unit, memory, and I/O of some kind. A microcontroller can be housed in a single chip, or might come in the form of a small circuit board.

mid-power model rocketry

Flying a rocket too big to be considered a low-power model rocket, but not large enough to need FAA clearance before flights. In general, mid-power model rockets are made from heavy cardboard tubes with aircraft plywood fins, and use F or G motors.

minimum diameter rocket

A rocket whose body tube is just big enough to hold the motor.

misfire

When the launch button is pressed and the rocket does not launch.

motor mount

The assembly used to hold the rocket motor in the main body tube.

motor retainer

The mechanism used to hold the motor in place.

multi-stage rocket

Rockets often use two or more stages. Each stage has a motor, fins, and its own recovery system. After the motor in a lower stage completes its burn, the stage separates, allowing the upper stage to continue its flight without the weight and drag of the lower stage.

NAR Pink Book

The official set of rules for NAR contests. It is available online at the NAR website.

NARAM

An annual, week-long NAR event, featuring sport launches, contests, and vendors.

National Association of Rocketry (NAR)

NAR is one of two organizations in the US that offer high-power rocketry certifications. It is also the oldest rocketry organization. NAR is particularly active in low-power rocketry; it sponsors the annual TARC competition and provides safety codes and insurance for high-power rocketry through O motors.

newton

A measure of force. One newton (N) is one kilogram-meter/second^2. It is equal to about 0.2248 pounds of force.

Newton’s third law of motion

For every action, there is an equal and opposite reaction.

newton-second

One newton of force applied for one second. The most common unit of measure for model rocket motor impulse, abbreviated N-s.

nichrome wire

A nickel and chromium alloy wire that heats when current is applied. Frequently used in igniters.

Nomex

A registered trademark for a flame-resistant material. Nomex cloth is often used to protect parachutes, Nomex string or cord is sometimes used for shock cords, and tubes of Nomex webbed material are often used as shock cord protectors.

normal force

A force at right angles to a direction. In model rockets, the normal force is used extensively in stability analysis, where it refers to a force that is at right angles to the main axis of the rocket.

nose blow recovery

A form of tumble recovery used for small, light rockets. The nose cone is ejected, remaining attached to the rocket with a shock cord, but there is no parachute or streamer. The shape of the rocket keeps it from returning to the ground ballistically.

nose cone

The tip of most rockets, which gradually narrows to a point or small blunt end. In most cases, the nose cone is a separate plastic or balsa wood piece that slips into the top end of the body tube.

nozzle

The part of the rocket motor that speeds up and directs the flow of ejected material. In the rockets from this book, this is generally some sort of clay or plastic construction from which the gas shoots.

O-ring

A ring of material, usually something flexible like rubber, used as a pressure seal. O-rings are used in water rockets to seal the launcher and in reloadable rocket motors to prevent hot gases from reaching the metal rocket motor case.

odd rockets

Also called oddrocs, these are rockets that just don’t look like normal rockets. They can be anything from a rocket with strange fins to a flying pig.

ogive nose cone

A nose cone with a shape that is a segment of a circle.

Ohm’s law

The relation between voltage, resistance, and current in a circuit: $V = IR$.

open track

When tracking with two theodolites, it’s possible for the altitude reported by the two trackers to differ. Under NAR contest rules, if the difference in altitude is more than 10% of the altitude, the altitude measurement is called an open track, and is not considered valid. See also *closed track*.

packing size

The amount of space needed for something carried in the rocket, such as a parachute or shock cord.

parabolic nose cone

A nose cone with a cross section formed from a mathematical shape called a parabolic series.

parachute

A large plastic or fabric umbrella-like device used to slow the descent of a model rocket.

parachute protector

A flame-resistant cloth used to protect the parachute, and sometimes the shock cord, from hot ejection charge gases. Also called a flame blanket or recovery blanket.

pascal

A unit used for pressure, stress, or tensile strength, a pascal is one kilogram/(meter second^2). The pascal-second, abbreviated Pa-s, is a unit used to measure viscosity in fluids.

perihelion

The point in an orbit when an object is closest to the Sun.

Pink Book

See *NAR Pink Book*.

piston ejection

Uses a bulkhead and tube coupler to form a piston in the main body tube, protecting the parachute and most of the shock cord from hot ejection charge gases.

planform

The shape of a fin, such as rectangular or elliptical.

pop pod

A pop pod attaches to something else, usually a glider. It holds a motor and recovery system, and is designed to pop off of the airplane or mother ship when the ejection charge fires.

power

See *impulse*.

power series nose cone

A nose cone with a profile in the shape of a mathematical curve called a power series.

pressure drag

The component of drag resulting from air molecules bouncing off of the surface of a rocket. It is sometimes called form drag or profile drag.

pressure separation

When a rocket pops apart early due to high pressure inside the rocket relative to the outside atmospheric pressure, which drops as the rocket gains altitude.

profile drag

Another name for pressure drag.

pylon

An extension on an aircraft or rocket intended for attaching something.

pyrogen

A flammable plastic that lights at a relatively low temperature but burns at a high temperature. It is typically used as the tip of an igniter, where it starts to burn due to the heat from an electric current flowing through a wire, and in turn ignites the black powder or ammonium perchlorate rocket fuel.

rail button

A small device affixed to the side of the rocket that slips into a launch rail. The shape varies, but a common shape is a short round cylinder with a notch, giving the device its name. Guides the rocket until it picks up enough speed for the fins to keep it stable.

Range Control Officer (RCO)

Another name for the Launch Control Officer (LCO).
See *Launch Control Officer*.

Range Safety Officer (RSO)

The person responsible for maintaining safe operations at the launch site. The RSO has the final say on any safety question.

RCO

Range Control Officer.

recovery blanket

See *parachute protector*.

recovery charge

See *ejection charge*.

recovery wadding

Flame-resistant material inserted into the body tube of a rocket to protect the parachute from the heat of the ejection charge.

reloadable motor

A rocket motor that can be reused after a flight, like the boosters on the Space Shuttle. In model rocketry, most reloadable motors are made with an aluminum tube and end caps, all of which are reusable. The motor liner, nozzle, various O-rings, and rocket fuel are disposable, and are cleaned from the case after each flight.

resistance

In electronics, resistance is the opposition to passing electric current. See *Ohm’s law*.

Reynolds number

The ratio of inertial forces to viscous forces, the Reynolds number is a key property of liquids and gases used when computing drag.

rocket simulator

See *simulator*.

rod whip

When a long launch rod flexes back and forth as the rocket lifts off. It can be violent enough to whack the rocket at the end of the rod, causing serious damage. In general, 1/8” launch rods should be 3 or, at most, 4 feet long. A 3/16” launch rod is usually acceptable up to about 6 feet long and will work fine for low-power rockets, but you will want a thicker rod or launch rail to support heavy mid-power and high-power rockets.

root

See *fin root*.

root chord

The length of the fin that attaches to the body tube.

RSO

Range Safety Officer.

rudder

On an airplane, the rudder is the part that sticks up or down from the fuselage. It is also called the vertical stabilizer.

safety cap

A blunt cap put on top of a launch rod to reduce the danger of injury if someone trips and falls on the launch rod.

safety interlock

The part of a launch controller that disables the controller until a launch key is inserted.

sanding block

A small piece of wood around which sandpaper is wrapped to allow sanding flat surfaces.

Schrader valve

The kind of valve commonly used on tires. The Schrader valve fits most common bicycle and car pumps.

screw eye

A screw with a metal loop on the head, frequently used in model rockets to form an attachment point for parachutes and shock cords at the base of a balsa nose cone.

semi chord

The length from the center of the root of a fin to the center of the tip. This length is important for stability analysis.

semi-span

The length from the root of the fin to the fin tip measured perpendicular to the body tube.

servo

A small package containing a motor and associated electronics that allow the motor to be positioned accurately based on a timed input signal. The kind of servos typically used in model rockets are designed for use in model airplanes.

shear pin

A thin rod or bolt used to fasten parts of a rocket together, but designed to break when the ejection charge fires.

shock cord

Attaches the rocket to the parachute or nose cone. Typically made from strips of rubber or elastic, shock cords on larger rockets may be made from nylon cord or rope.

shoulder

The part of a nose cone or payload bay that slides into the body tube.

shoulder length

The distance a nose cone or payload bay shoulder slides into the body tube.

shroud lines

The strings on a parachute that connect the parachute to the rocket.

side deployment

A parachute ejection method commonly used for water rockets. The parachute deploys through a door in the side of the rocket rather than pushing out of the top of the rocket.

simulator

A computer program that takes the design of the rocket and predicts whether the rocket will be stable, how high and fast it will fly, what delay time is needed, and so forth.

skin friction drag coefficient

This specialized drag coefficient is used when finding the friction drag on a rocket. It accounts for the roughness of the finish, which can cause the air flow to switch from laminar flow to turbulent flow, increasing the drag.

sled

A carrier used to hold smaller components that slides into the rocket. This is typically a flat plywood or plastic plank used for mounting altimeters and other components that slides into the payload bay of the rocket.

slug

In biology, a small, slimy animal. In physics, a unit of mass in the imperial system. The units are pounds-seconds^2/feet, so one slug is the mass of an object that requires a force of one pound to accelerate it at a rate of one foot/second^2.

solid-propellant motor

A motor powered by chemical combustion of a material that includes both the propellant and an oxidizer. This means these motors don’t need an external supply of air to burn. Typical solid propellants for model rocketry include black powder and ammonium perchlorate.

snap swivel

Snap swivels are used at the end of shock cords and parachutes to make it easier to change the payload bay or parachute on a rocket. A snap swivel has a clasp at one end that opens and closes for easy removal, and a loop at the other end where the parachute or shock cord is tied. They can be found with fishing supplies.

span

The distance from one fin tip to the opposite fin tip, assuming there are four fins on the rocket. It is also twice the distance from the fin tip to the center of the body tube. Used when calculating drag. When describing a fin in most other circumstances, the span is the distance from the fin tip to the root chord in a direction perpendicular to the body tube.

specific impulse

A way to measure the efficiency of rocket fuel. It represents the force generated with respect to the material used in a given amount of time.

spectator

Anyone at a launch site not specifically involved in the launch.

spill hole

A hole cut into the top of a parachute to make it more stable.

squib

A small charge and an igniter, often used to separate rocket parts or eject parachutes.

stability

The tendency of the rocket to fly straight. We obtain stability by making sure the center of pressure for the rocket is about one to two body tube diameters behind the center of gravity.

stable equilibrium

When a rocket is properly designed, it will fly in stable equilibrium. This means if something nudges the rocket so it is not pointed in the direction of flight, it will return itself to the proper orientation.

standard deviation

A standard deviation is a value from probability theory. For our purposes, if you measure something—say the altitude of a model rocket—and give the standard deviation, you are claiming that the actual altitude has a 68% chance of being within one standard deviation. For example, if the altitude is 350±25 feet, you are saying the actual altitude has a 68% chance of being between 325 feet and 375 feet. Extending the concept, the actual altitude has a 95% chance of being in the range of 300 feet to 400 feet, and a 99.7% chance of being within three standard deviations, or 275 feet to 425 feet.

static stability

The process of finding the center of pressure and center of gravity, then using these values to determine if a rocket is stable, is called analyzing the static stability of the rocket. See also *dynamic stability*.

streamer

A long, thin ribbon of material used instead of a parachute, especially in light rockets that fly very high.

streamlining

In aerodynamics, streamlining refers to selecting a shape to minimize the force of drag.

subsonic region of flight

Literally, flight at less than the speed of sound. But since the transonic region is so important for understanding flight, subsonic flight usually means flight below about Mach 0.8 when discussing aerodynamics.

supersonic region of flight

Literally, flight faster than the speed of sound. In aerodynamics, though, supersonic flight often means flight above Mach 1.2, since the transonic region from Mach 0.8 to Mach 1.2 behaves very differently from speeds above and below this range.

surface mount fins

The practice of fastening a fin flush against the wall of the outer body tube. See also *through-the-wall fins*.

sweep length

The distance from the leading edge of the fin where it attaches to the body tube to the leading edge of the fin at the tip, measured parallel to the body tube.

tang

In a through-the-wall fin, the part of the fin that is inside the outer body tube. Also called the fin tab.

tangent

The length of the opposite side of a triangle divided by the length of the adjacent side, where the opposite and adjacent sides must meet in a right angle.

tangent ogive nose cone

A nose cone with a profile formed from a segment of a circle; the place where the nose cone meets the body is tangent to the circle, forming a smooth joint.

theodolite

A device used to measure angles. It reports the angle from the horizontal to a point above or below the horizontal (the elevation angle), and the angle from a reference point to an object along the horizontal plane (the azimuth angle). In model rocketry, two or more theodolites are used to optically track model rockets.

thermal cycling

Changes in temperature over time. This is an important consideration for some kinds of rocket motors and fuels, particularly single-use black powder motors, which can separate or crack after too many cycles from hot to cold temperatures.

through-the-wall fins

Fins that pass through a slot in the outer body tube of a rocket, attaching to an inner tube. This provides vastly stronger fin attachment.

thrust

The force from a rocket motor that propels the rocket. Thrust is usually measured in newtons. A newton is one kg m/s^2.

thrust curve

A plot of the thrust from a motor as a function of time.

tip chord

The length of the flat tip of a trapezoidal fin.

total impulse

A measure of the overall power of a rocket motor. It is the average thrust delivered by the motor times the number of seconds for which the thrust is delivered. Total impulse is usually measured in newton-seconds (N-s), although it is occasionally measured in pound-seconds or other units.

total power

See *total impulse*.

tower launcher

Used for model rockets that do not have a launch lug. It uses three stiff rails or rods that form a cage around the rocket to guide it for the first few feet of the flight. These rails or rods are sometimes adjustable for different body tube diameters.

TRA

A common abbreviation for the Tripoli Rocketry Association.

trailing edge

The part of the rocket—for example, the edge farthest from the nose cone—where the air leaves the rocket. Usually used when referring to a fin or wing.

transonic region of flight

Generally defined as Mach 0.8 to Mach 1.2, the speed at which the effects of subsonic and supersonic flight mix, causing flight behavior that is very different from flight well below or well above the speed of sound.

Tripoli Rocketry Association (TRA)

TRA is one of two organizations in the US that offer high-power rocketry certifications. While TRA covers rocketry from low power up, it is especially active in high-power rocketry and amateur rocketry, including rockets above O power and rocket motor construction.

tube coupler

A small tube that slips inside a body tube, used to join two pieces of body tube to make a longer tube. Tube couplers are usually made from a denser, stronger paper material than the body tubes. Tube couplers are also used on payloads so they slip into a body tube like a nose cone, in some motor mounts, and for all sorts of other creative tasks.

tumble recovery

Some rockets are light enough that they do not need a parachute or streamer, but they are still too heavy to return ballistically. In such cases tumble recovery is often used, where something changes the geometry of the rocket so it is no longer stable. The rocket tumbles as it falls back to earth, slowing it enough for a safe landing.

turbulent flow

The flow of a fluid past an object with much mixing and swirling. See also *laminar flow*.

two-stage rocket

See *multi-stage rocket*.

unstable

A rocket that does not fly properly is unstable. This usually means the center of gravity was not at least one body tube diameter in front of the center of pressure.

unstable equilibrium

Unstable equilibrium occurs when something is in a particular state, such as a rocket with the nose pointed in the direction of flight, but a slight disturbance will start a process that will push it further and further from the equilibrium state. The rocket will be unstable.

vent hole

A small hole used to allow pressure inside and outside the rocket to equalize.

vertical stabilizer

On an airplane, the vertical stabilizer is the part that sticks up or down from the fuselage. It is also called the rudder.

viscous forces

The forces from the molecules of the fluid or gas through which the object is moving sticking to an object. The ratio of inertial force to viscous force is the Reynolds number.

voltage

The electric pressure in a circuit. See *Ohm’s law*.

Von Kárman nose cone

A special case of the Haack series nose cone, the Von Kárman nose cone is formed by setting one of the terms in the Haack series to zero.

vortex

In aerodynamics, a vortex is a twirling motion of air, like that seen at the tip of a wing or fin that is producing lift.

weathercocking

An overly stable rocket tends to turn into the wind very quickly. If the rocket is traveling slowly as it leaves the pad and the wind is fairly strong, an overly stable rocket can rapidly turn into the wind. This is called weathercocking. In severe cases, the rocket can end up in powered flight traveling in a horizontal direction.

wetted surface

The surface area of the rocket that is exposed to the air. A larger wetted surface generally means a large friction drag.

white glue

White glue, such as Elmer’s Glue, is similar to wood glue. It comes in plastic squeeze bottles. While wood glue is a bit better, white glue is a perfectly adequate substitute for wood glue when building small paper and wood model rockets. It’s also a common supply item for schools, making it convenient for school rocketry projects.

wood glue

Wood glue is great for gluing wood and paper. It forms a bond that is generally stronger than the original wood or paper. If you glue a fin to a body tube with wood glue, the body tube will generally tear or the fin will break—but the wood glue will remain intact.

Z-folding

A way of folding shock cords so they take up less space in the rocket.

zipper

One of the failures that can occur when a parachute ejects when the rocket is traveling too fast is a zipper. This is when the parachute and shock cord don’t fail, but the speed is high enough to rip the body tube open with the shock cord. This is rare in low-power model rockets, which tend to use elastic shock cords. It’s pretty common in mid- and high-power rockets that use nylon shock cords.

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